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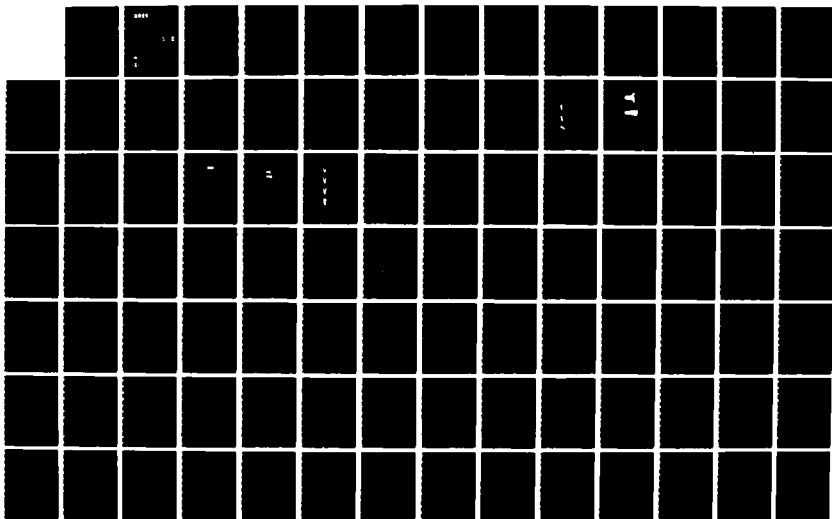
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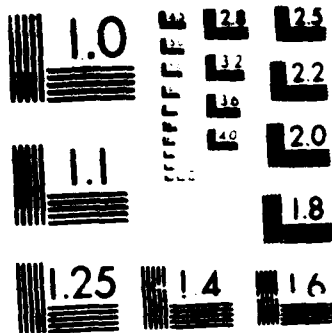
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## SUFFIELD MEMORANDUM

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**SFFSTAB:**

**A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC  
STABILITY OF A SELF-FORGING FRAGMENT (U)**

by

C.A. Weickert

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SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE  
AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

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C.A. Weickert

ABSTRACT

↓  
An aerodynamic stability computer program (SFFSTAB) has been developed for calculating the spin rate required for stabilization of a self-forging fragment. An aerodynamic stability criterion which combined gyroscopic and dynamic stability was used together with a technique for calculating aerodynamic coefficients. SFFSTAB is a useful tool for conducting aerodynamic stability parameter studies for different fragment shapes. Complete documentation of the computer program including sample problem, flowchart and FORTRAN listing is provided.

(Keywords: explosions, fragments, computer program)

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NOMENCLATURE

Symbol	Description
A	axial force
$C_D$	drag coefficient
CG	center of mass
$C_m$	pitching-moment coefficient
$C_{m_{p\alpha}}$	derivative of the magnus-moment coefficient
$(C_{m_q} + C_{m_{\dot{\alpha}}})$	pitch-damping coefficient
$C_{m_{\alpha}}$	$\frac{dC_m}{d\alpha}$ ; derivative of pitching-moment coefficient
$C_N$	normal-force coefficient
$C_{N_{\alpha}}$	derivative of the normal-force coefficient
$C_p$	pressure coefficient
CP	center of pressure

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NOMENCLATURE (cont'd)

$d$	projectile diameter
$d_b$	base diameter of projectile
$d_n$	base diameter of segment
$D$	drag force
$I_x$	axial moment of inertia
$I_y$	transverse moment of inertia
$K_x$	dimensionless axial radius of gyration
$K_y$	dimensionless transverse radius of gyration
$l$	projectile length
$L$	lift force or distance from the Magnus center of pressure to the center of gravity
$\ell$	length of segment
$M$	Mach number
$m$	mass
$N$	normal force

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NOMENCLATURE (cont'd)

$P$	projectile spin rate
$R$	resultant force
$R_1$	Reynolds Number based on 1
$S$	projectile cross-sectional area
$S_d$	dynamic stability factor
$S_g$	gyroscopic stability factor
$V$	velocity
$\alpha$	angle of attack
$\theta$	angle between surface tangent and free stream or flare angle
$\rho$	density

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AERODYNAMIC STABILITY OF A SELF-FORGING FRAGMENT

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1.0 INTRODUCTION

The purpose of this report is to describe the criteria for stability and to document a program which is capable of calculating aerodynamic coefficients and spin rates required for stabilization of self-forging fragments.

The Demolitions Group at the Defence Research Establishment Suffield (DRES) is responsible for military related research in Canada on demolitions and demolition devices. DRES is developing a Self-Forging Fragment (SFF) technology base suitable for the study of the application of SFF devices to demolition problems.

One of the projects currently under study is the application of spin stabilization to self-forging fragments. The project requires both numerical and experimental capabilities to study the SFF formation and flight stability.

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The DRES Flash X-ray Facility has the capability of obtaining formation, shape, stability characteristics and trajectory data for the fragments. The fragments can be monitored over a 60 m flight path by using a combination of X-ray radiographs and yaw screens. To fulfill the numerical requirements, and the requirement for a code to determine what parameters to vary, a computer program was developed to calculate the aerodynamic coefficients for a self-forging fragment and to predict its stability.

Section 2 describes self-forging devices and the fragment characteristics, including selected results from experimental tests. In Section 3 aerodynamic stability criteria are presented. Section 4 describes the computer program Self-Forging Fragment STABility (SFFSTAB). The results for sample problems are also described in this section.

The DATCOM [3] method for obtaining aerodynamic coefficients is documented in Appendix A, and properties of spherical segments and truncated cones are given in Appendix B. A flowchart and a FORTRAN listing of the computer program with input and output for the sample problem presented in Section 4 are contained in Appendix C.

## 2.0 SELF-FORGING FRAGMENT DEVICE

A typical self-forging fragment (SFF) device, as illustrated in Figure 1, consists of a body which is filled with high explosive (HE) and a metal liner. The charge is initiated by a detonator and an explosive booster. Upon initiation, the resulting detonation wave travels through the HE subjecting the metal liner to high forces causing a single fragment to be formed, and accelerating this fragment to a high velocity. Typical SFF's have initial velocities of

2-3 km/sec. These fragments can travel to distances well in excess of 1000 calibers, beyond which accuracy becomes a problem.

In many self-forging fragment designs, the objective is to produce a long rod-type fragment as opposed to a ball-type fragment since the former has, in general, greater target penetration capability. However, a long fragment is inherently unstable in flight as illustrated in Figure 2. This figure shows flash radiographs of the fragment as it deviates from the intended flight path. This instability results in a loss of accuracy and a lower target penetration capability. Current SFF designs use a flared tail fragment. This feature increases the stability of the fragment and improves its accuracy. However, the flared tail increases the aerodynamic drag on the fragment, resulting in a shorter flight path, and it also reduces the penetrating capability of the fragment since the tail does not contribute to the penetration process. If a fragment could be spin stabilized, the requirement for a flared tail would be eliminated (see Figure 3). This would result in increased performance of the self-forging fragment device. The main aim of this report is to present a computer program for calculating the requirements for aerodynamic stability and to illustrate its application to self-forging fragments with flared rod and blunt cone shapes.

### 3.0 AERODYNAMICS OF SELF-FORGING FRAGMENTS

Determination of the aerodynamic stability of a projectile requires a knowledge of the mass distribution within the projectile (i.e., location of the center of gravity, moments of inertia) and the aerodynamic parameters (i.e., lift, drag, etc.). For most projectiles the mass distribution can be calculated or measured from the projectile design and the aerodynamic parameters can be determined by wind tunnel

experiments. However, for self-forging fragments the actual shape of the fragment that will be formed from a liner is unknown, so that these properties cannot be determined a priori. Flash X-radiography can be used to determine the outer profile of the fragment but in general, unless very high-energy X-rays are used, the radiographs do not reveal any information about the interior of the fragment. Also, the high velocities of self-forging fragments requires that very specialized hypersonic tunnels be used to measure the aerodynamic parameters. Numerical techniques are therefore used to calculate the self-forging fragment stability. This report describes the SFFSTAB code developed for this purpose. After a review of the aerodynamic forces and moments acting on a projectile, formulas for gyroscopic and dynamic stability used in a stability criterion derived by Murphy [2] are presented. Aerodynamic coefficients required for the stability formulas are provided by the DATCOM method [3]. Results for typical fragment shapes are also presented.

The aerodynamic forces acting on a projectile are illustrated in Figures 4 and 5. The resultant (R) of the forces acting on a projectile can be decomposed into the drag force (D) and lift force (L) in the wind coordinate system, or the normal force (N) and axial force (A) in the body coordinate system. The resultant force (R) acts on the center of pressure (CP) which is the point at which the net moment is zero. An additional force which acts on a projectile is the magnus force (see Figure 5). The combination of the air flowing over the projectile and the spin of the projectile results in an asymmetric boundary layer thickness distribution. This effectively changes the aerodynamic shape of the body which results in a force normal to the angle of attack plane.

The location of the center of pressure (CP) depends on the velocity of the projectile. Therefore, it is more convenient to use

the center of gravity (CG) or center of mass which depends only on the mass distribution in the projectile. The forces acting at the center of pressure are replaced by an equivalent force and moment combination at the center of gravity. The aerodynamic forces and moments are usually non-dimensionalized. The corresponding force and moment coefficients,  $C_{\text{FORCE}}$  and  $C_{\text{MOMENT}}$ , take the general forms:

$$C_{\text{FORCE}} = \text{FORCE} / \frac{1}{2}\rho V^2 S, \quad (3.1)$$

$$C_{\text{MOMENT}} = \text{MOMENT} / \frac{1}{2}\rho V^2 S l, \quad (3.2)$$

where  $\rho$  and  $V$  are the air density and velocity respectively,  $S$  is the projectile cross-sectional area, and  $l$  is the projectile length.

The dominant aerodynamic effect is the pitching-moment or static-moment coefficient ( $C_m$ ). This coefficient represents the overturning or pitching moment which is a function of the distance between the centers of mass (CG) and pressure (CP). If the derivative of the pitching moment ( $C_{m_\alpha}$ ) with respect to the angle of attack ( $\alpha$ ) is negative, the CP is located behind the CG and the projectile is said to be statically stable (i.e., stable as long as it is not perturbed). Conversely, if  $C_{m_\alpha}$  is greater than zero, then the CP is located ahead of the CG and the projectile is statically unstable. Physically, the center of gravity is the pivot point of the projectile. The resultant force ( $R$ ) acts at the center of pressure in a direction towards the rear of the projectile. Thus, if the force acts ahead of the pivot point the projectile is statically unstable, and conversely if it acts behind the pivot point the projectile is statically stable.

Stabilization of projectiles is accomplished by two techniques, fin and spin stabilization. Fin stabilization is accomplished by

adding fins (or a flared tail in the case of a self-forging fragment) to the projectile in order to shift the center of pressure behind the center of gravity. In the second technique, the projectile is spun in order to maintain the center of pressure as close as possible to the trajectory which is the path of the center of mass. For a spinning projectile a gyroscopic stability factor ( $S_g$ ) is defined by Murphy [2] as:

$$S_g = \frac{2}{\pi \rho} \frac{I_x^2}{I_y} \left( \frac{P}{V} \right)^2 \frac{1}{C_{m_\alpha}} \frac{1}{d^3}, \quad (3.3)$$

where  $P$  and  $V$  are the projectile spin rate and velocity,  $\rho$  is the air density,  $d$  is the projectile diameter,  $C_{m_\alpha}$  is the derivative of the pitching-moment coefficient, and  $I_x$  and  $I_y$  are the axial and transverse moments of inertia, respectively. The dominant aerodynamic coefficient affecting the motion of a spinning projectile is the pitching-moment coefficient. In order for a statically unstable projectile to have a periodic motion (i.e., continue to spin) and not tumble, the gyroscopic stability factor ( $S_g$ ) must be greater than one. Physically the motion in this case is the same as that of a spinning top. Gyroscopic stability, like static stability (i.e., center of pressure behind the center of gravity) is required for stable oscillatory motion, but this alone does not ensure that small perturbations acting on the projectile will not grow and result in unstable motion. In order to characterize the response to small perturbations, a dynamic stability factor ( $S_d$ ) was derived by Murphy [2] from the equations of motion of a spinning projectile. This stability factor is:



$$S_d = \frac{2 (C_{N_\alpha} - C_D) + 2 K_x^{-2} C_{m_{p\alpha}}}{C_{N_\alpha} - 2C_D - K_y^{-2} (C_{mq} + C_{m_\alpha})}, \quad (3.4)$$

where  $K_x$  and  $K_y$  are the dimensionless axial and transverse radii of gyration, respectively, the sum  $(C_{mq} + C_{m_\alpha})$  is the pitch-damping coefficient,  $C_{N_\alpha}$  and  $C_{m_{p\alpha}}$  are the derivatives of the normal-force and Magnus-moment coefficients, respectively, and  $C_D$  is the drag coefficient.

The relation between the spin rate of a projectile and various types of projectile stability was characterized by Murphy [2]. His results are summarized on the stability diagram shown in Figure 6. The boundary between dynamic stability and instability is given by the equation:

$$\frac{1}{S_g} = S_d (2 - S_d). \quad (3.5)$$

This equation can be used in conjunction with equation (3.3) to determine the stability bounds on the projectile spin rate ( $P$ ). The following conclusions can be made by referring to Figure 6:

- (1) A dynamically stable projectile must be gyroscopically stable (i.e.,  $\frac{1}{S_g} < 1$ );
- (2) If  $S_d$  lies in the interval (0-2), a statically unstable projectile can be stabilized by spinning it at a sufficiently high rate and a statically stable projectile is always dynamically stable;

(3) If  $S_d$  lies outside this interval, a statically unstable projectile cannot be spin-stabilized. In fact, a statically stable projectile can be made dynamically unstable by spin.

It should be pointed out that the results shown in Figure 6 assume that  $S_d$  does not depend on the spin rate. If there is a strong dependence of the magnus moment on spin then the method of determining stability must be modified [2].

The effects of the various coefficients in equation (3.4) on the dynamic stability factor ( $S_d$ ) have been studied by Platou [5]. He presents a series of graphs that can be used as a guide to determine the influence of projectile design changes on the dynamic stability.

In order to apply the stability criterion described above, the mass distribution (moments of inertia, radii of gyration) and the aerodynamic coefficients in equations (3.3) and (3.4) must be known. As previously mentioned, determination of the aerodynamic coefficients for self-forging fragments by experimental wind tunnel testing is difficult and therefore numerical techniques are used for this purpose. A compendium of methods (DATCOM) for determining aerodynamic coefficients for subsonic to hypersonic velocity regimes has been assembled by the US Air Force [3]. For the case of hypersonic velocities (applicable to self-forging fragments), Newtonian impact theory is used to determine the pressure coefficient for any surface element. Fluid particles that impact the surface are assumed to lose their normal component of momentum, whereas the tangential component is preserved. The impact results in a pressure coefficient ( $C_p$ ) of the form

$$C_p = 2 \sin^2 \theta \quad (3.6)$$

where  $\theta$  is the angle between a tangent to the surface and the direction of the free stream of fluid particles. This pressure coefficient is then used to derive analytical expressions for the aerodynamic coefficients for a particular shape of projectile. The DATCOM method uses design charts and empirical relationships to determine the aerodynamic coefficients at hypersonic velocities for projectile shapes composed of one or more cone frustums with or without a spherical nose. As will be shown later these shapes can be used for self-forging fragments.

The method will now be illustrated for the derivative of the normal-force coefficient ( $C_{N_\alpha}$ ) which is given by

$$\frac{dC_N}{d\alpha} = C_{N_\alpha} = \sum_{n=1}^m \left( C_{N_{\alpha n}} \right) \left( \frac{d_n}{d_b} \right)^2 \quad (3.7)$$

where  $d_n$  and  $d_b$  are the base diameters of the segment and projectile, respectively. To apply this equation, the body is divided into  $m$  segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment being a cone frustum. The parameter  $C_{N_\alpha}$  for a spherical nose, based on its base area, is obtained from Figure 7, and  $C_{N_\alpha}$  for a cone frustum, based on the base area of the specific segment, is obtained from Figure 8. The ratio  $(d_n/d_b)^2$  refers  $C_{N_\alpha}$  to the base area of the configuration. By evaluating  $C_{N_\alpha}$  for each segment and then applying equation (3.7) the derivative of the normal-force coefficient ( $C_{N_\alpha}$ ) for the complete projectile is obtained. The method applied to the remainder of the aerodynamic coefficients (except for the derivative of the magnus moment coefficient ( $C_{m_{p\alpha}}$ )) is given in Appendix A. The derivative of the magnus moment coefficient ( $C_{m_{p\alpha}}$ ) can be determined from the following empirical equation [5]:

$$C_{m_{p.1}} = \frac{26.3 (1/d)^2 L}{\sqrt{R_1}} \quad (3.8)$$

where  $l$  and  $d$  are the projectile length and diameter, respectively,  $L$  is the distance from the magnus center of pressure to the center of gravity and  $R_1$  is the Reynolds Number based on  $l$ .

All of the information previously described in this section can be incorporated into a computer program for calculating aerodynamic stability of self-forging fragments.

#### 4.0 SFFSTAB: AERODYNAMIC STABILITY PROGRAM

A computer program SFFSTAB has been developed for calculating the aerodynamic stability of a self-forging fragment. In this program, physical properties such as volume, mass, and moments of inertia are first calculated. Formulas for these properties for hollow spherical segments and hollow truncated cones have been derived and are given in Appendix B. Next, the aerodynamic coefficients are computed using the DATCOM method (Appendix A). Gyroscopic and dynamic stability are calculated and the projectile's stability characteristics are determined from the stability criteria illustrated in Figure 6. If the fragment is dynamically unstable, but can be spin stabilized, then a minimum fragment spin rate for stabilization is calculated. Since the fragment is initially formed from a saucer-shaped liner, it is necessary to translate the fragment spin rate into a spin rate for the initial device configuration. This is simply done by dividing the liner into segments and applying conservation of angular momentum (see Figure 9).

As an example of the application of the SFFSTAB computer program consider the self-forging fragment radiograph shown in Figure 10.

As illustrated a five segment model was used to represent the fragment. The objective of the calculation was to determine the stability characteristics of this fragment and to determine if it could be spin stabilized. The actual output from the SFFSTAB program is given as the sample problem in Appendix C. For the solid fragment shape shown in Figure 10, the calculated minimum spin rate for stabilization was 66280 RPM. Based on conservation of angular momentum this corresponds to an initial SFF charge spin rate of 3860 RPM.

SFFSTAB is a useful tool for conducting parametric studies for different fragment shapes. The dependence of stability on the exterior shape is illustrated in Figure 11, where the fragment spin rate required for dynamic stability as a function of the flare angle  $\theta$  is shown for typical fragment shapes. The interior profile also has a significant effect on the dynamic stability. Some typical results obtained for fragments with similar exterior profiles but varying degrees of hollowness are shown in Figure 12. Notice that as the fragment shape is changed from hollow to completely solid the spin rate required for dynamic stability increases.

## 5.0 SUMMARY

In summary, an aerodynamic stability criterion which combined gyroscopic and dynamic stability has been presented. A technique for calculating the aerodynamic coefficients was used together with the stability criterion for calculating the stability of self-forging fragments. A computer program (SFFSTAB) was developed using this information and sample problems illustrating the effects of parameters such as interior and exterior fragment profiles have been presented. This report provides the complete documentation required to use the program SFFSTAB.

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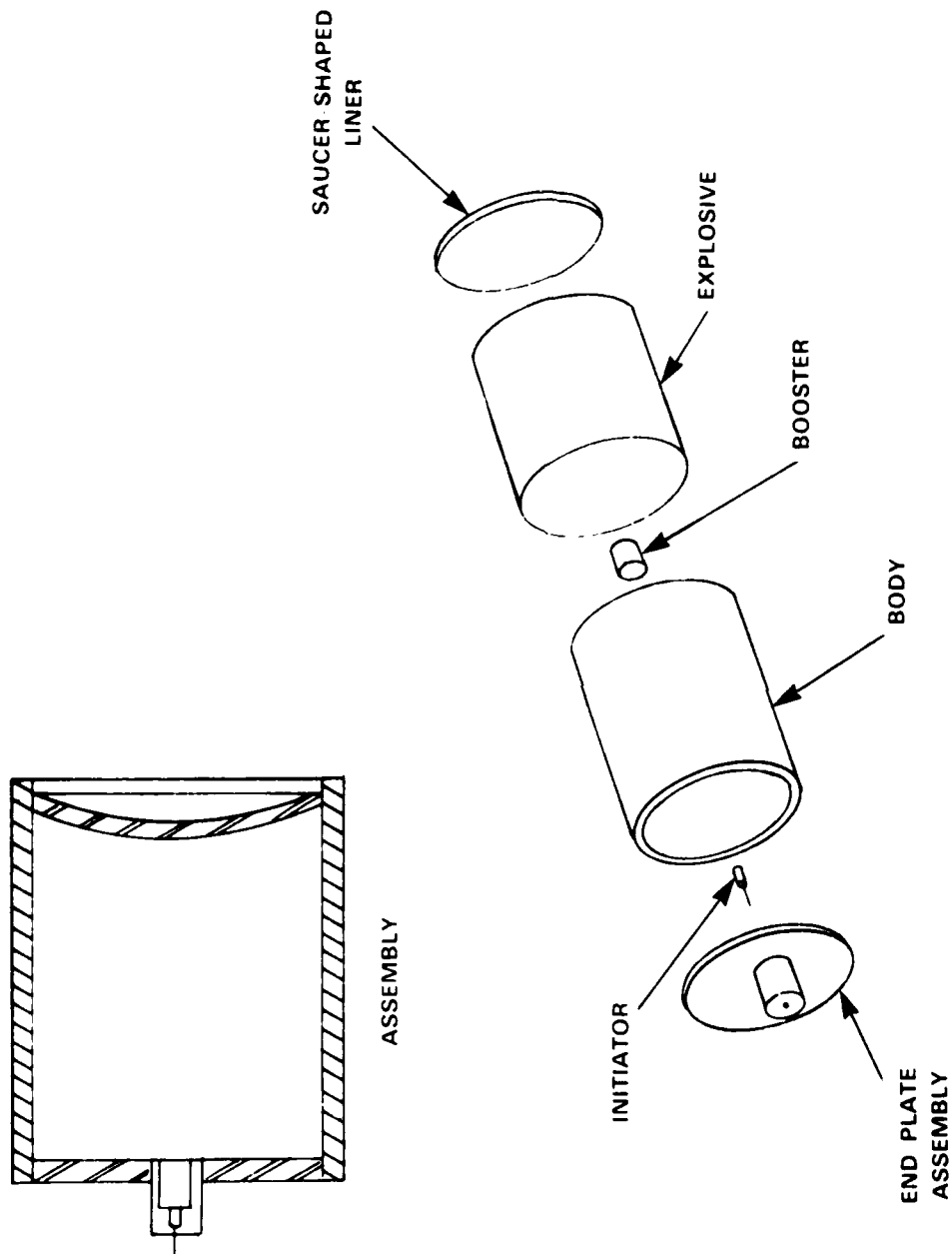


Figure 1  
SELF-FORGING FRAGMENT DEVICE  
Reference [1]

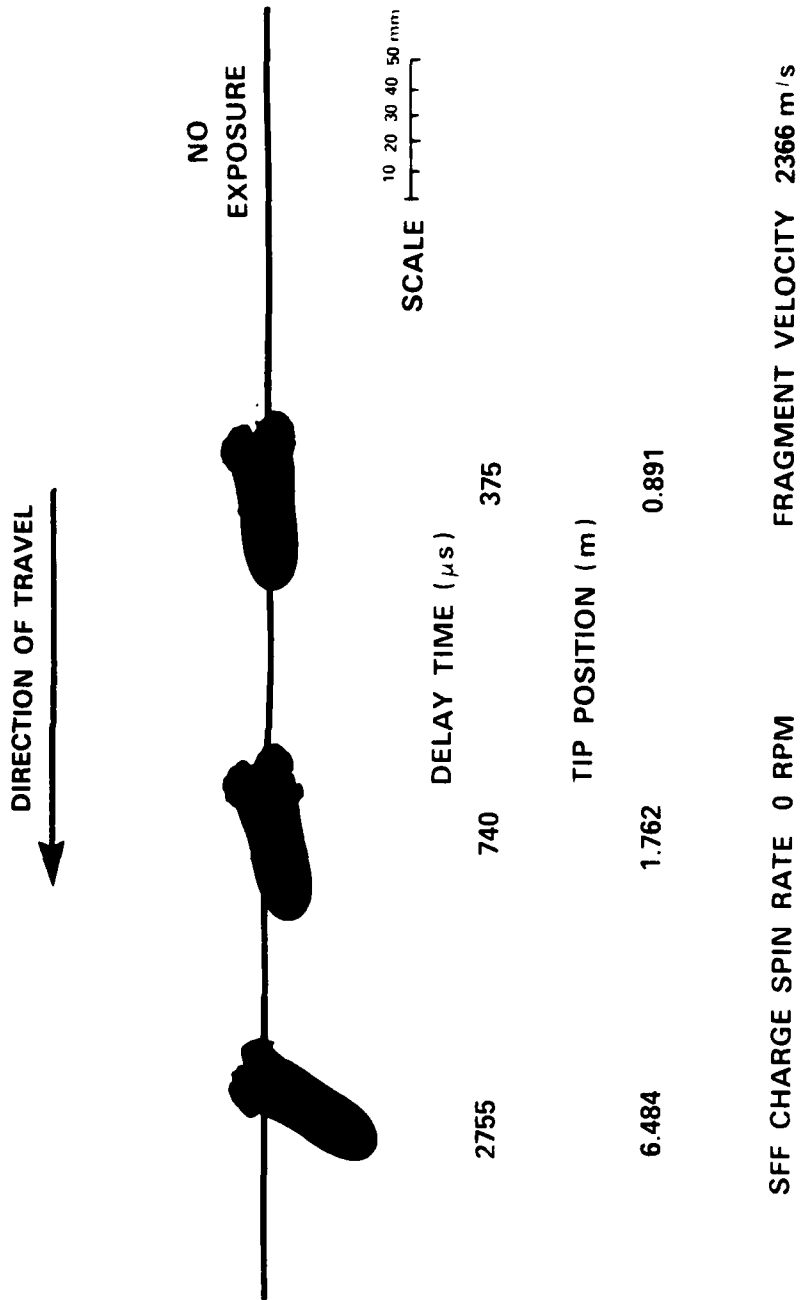


Figure 2

RADIOGRAPHS OF UNSTABLE FRAGMENT



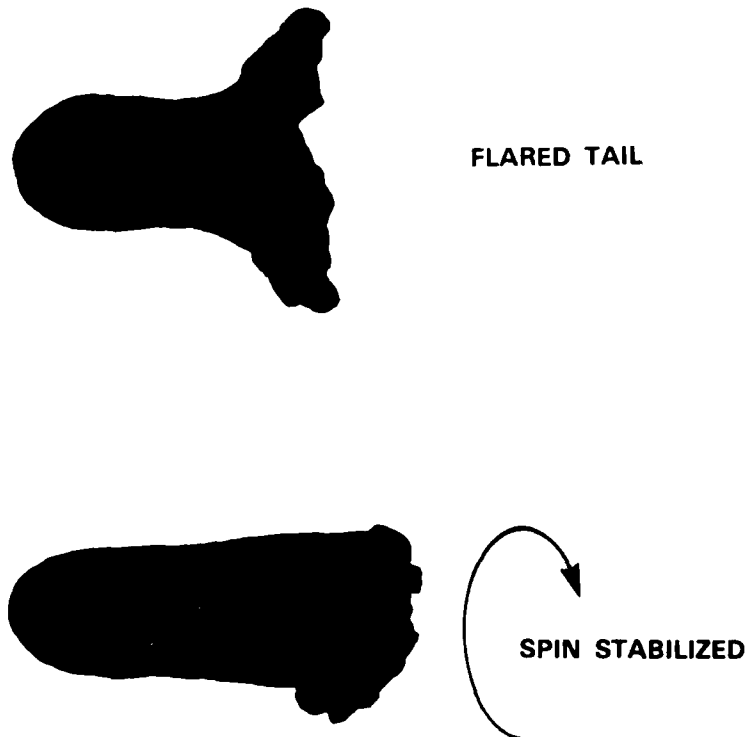
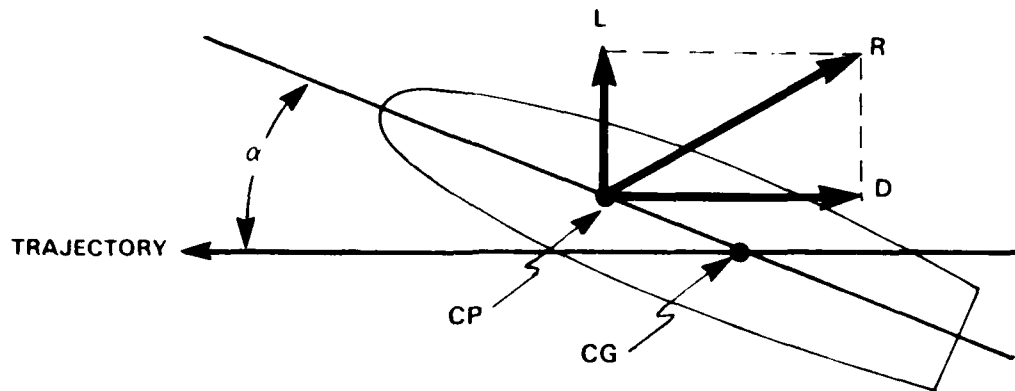
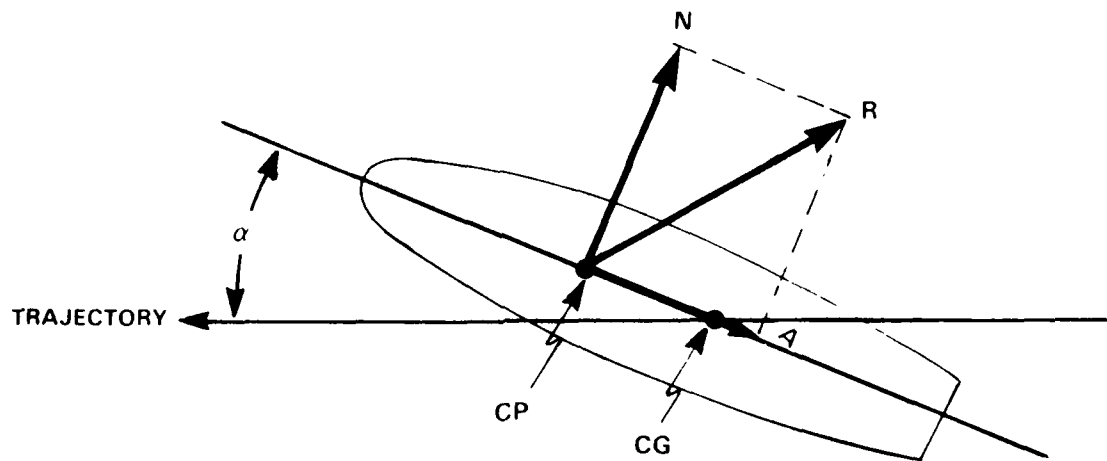


Figure 3

TECHNIQUES FOR SELF-FORGING FRAGMENT STABILIZATION



a) WIND COORDINATES



b) BODY COORDINATES

L	=	LIFT FORCE	A	AXIAL FORCE
D	=	DRAG FORCE	$\alpha$	ANGLE OF ATTACK
R	=	RESULTANT FORCE	CP	CENTER OF PRESSURE
N	=	NORMAL FORCE	CG	CENTER OF GRAVITY

Figure 4

## AERODYNAMIC FORCES ON A BODY

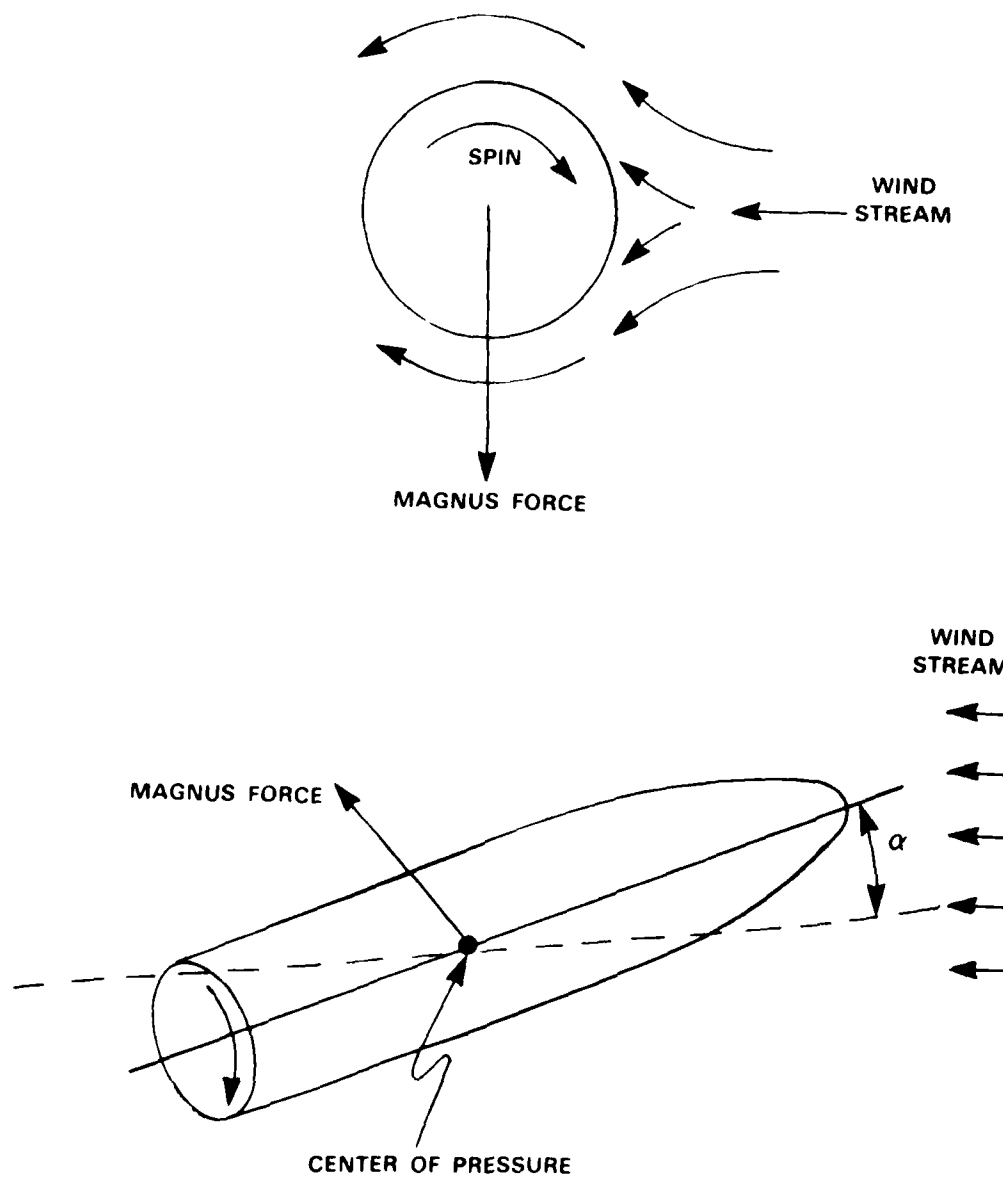


Figure 5  
MAGNUS FORCE (Reference [4])

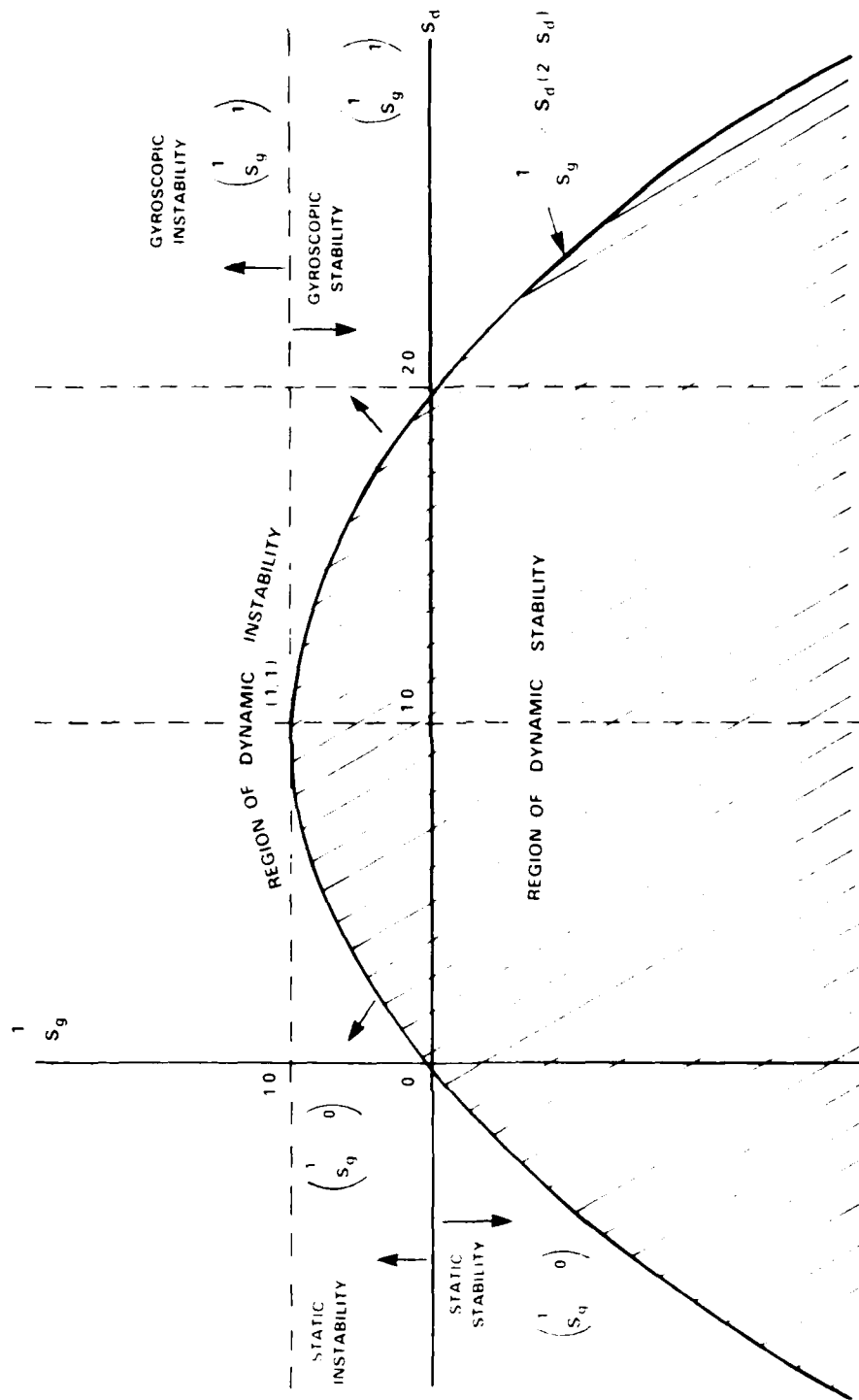


Figure 6

STABILITY DIAGRAM  $\frac{1}{S_g}$  VS  $S_d$ , WHERE  $S_g$  = GYROSCOPIC STABILITY  
AND  $S_d$  = DYNAMIC STABILITY (Reference [2])

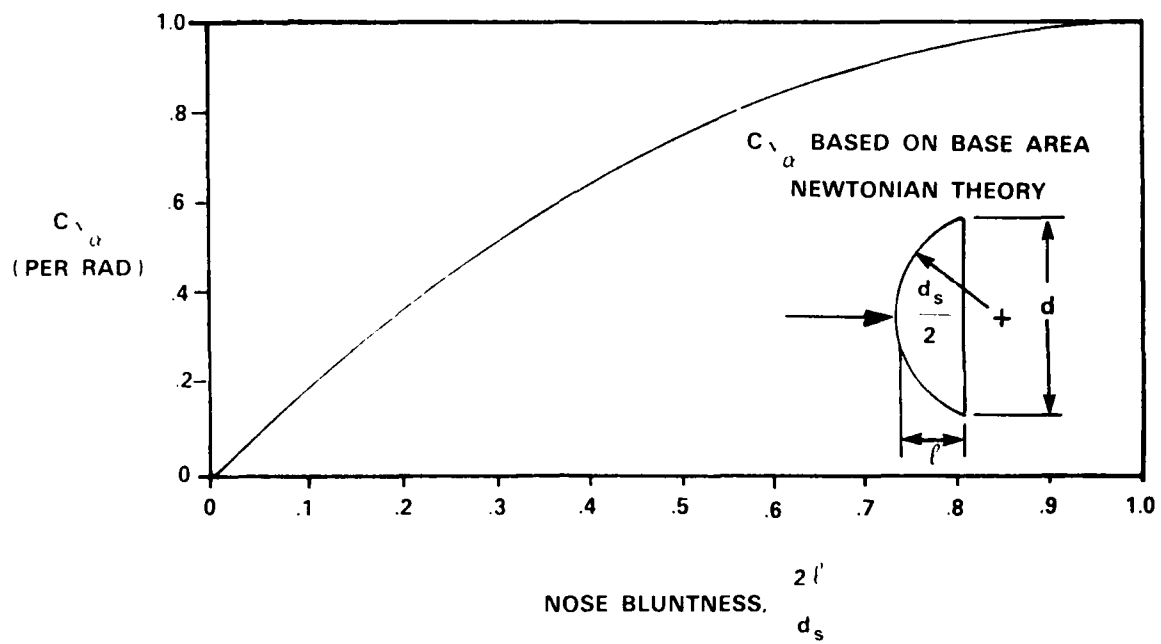
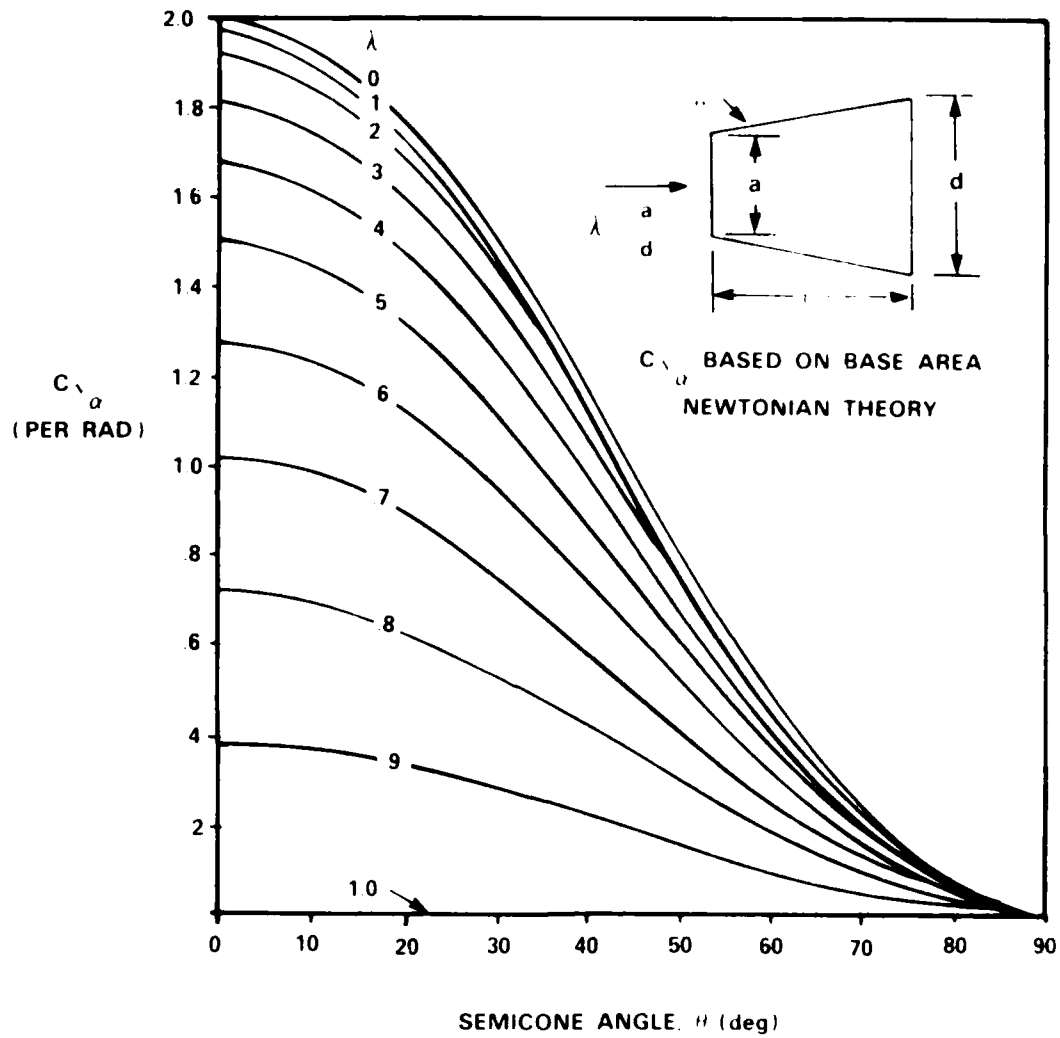
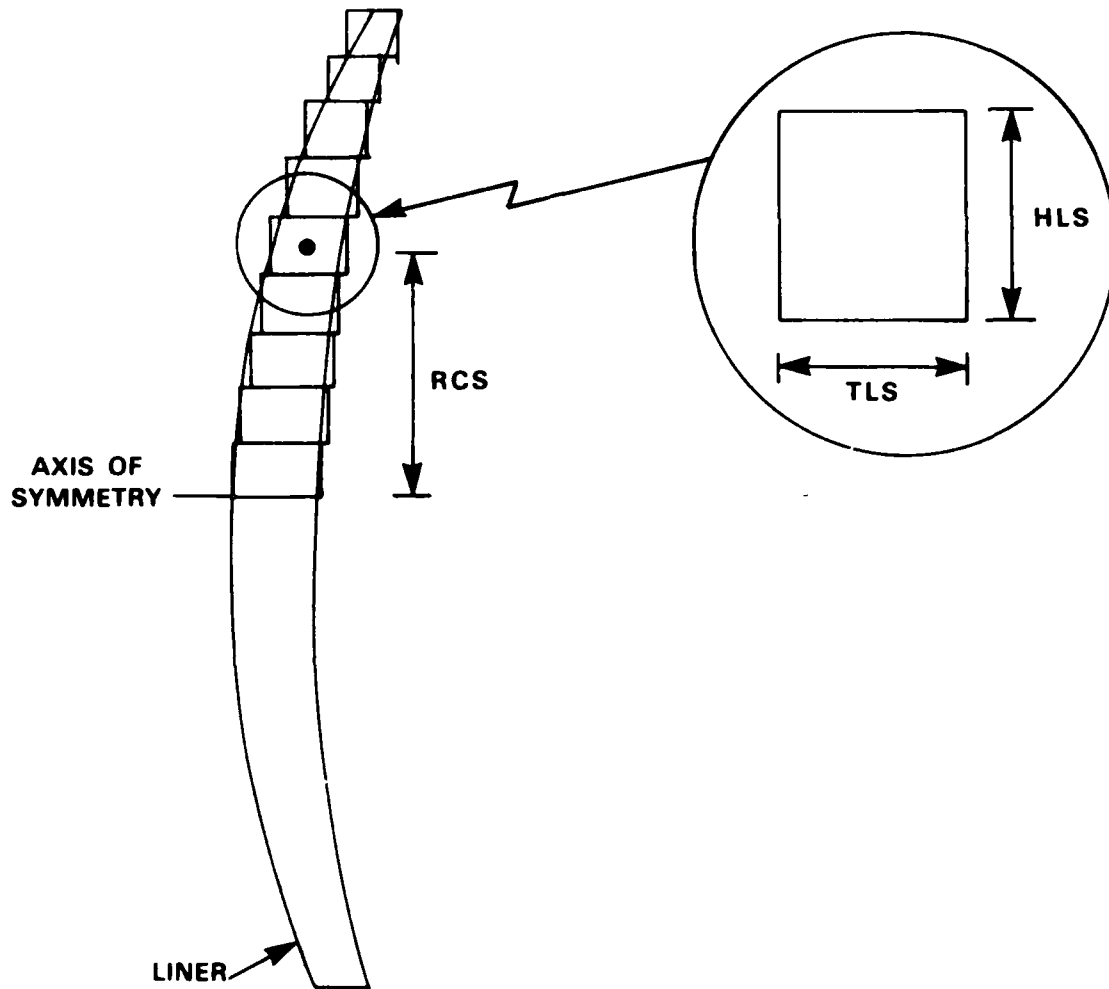


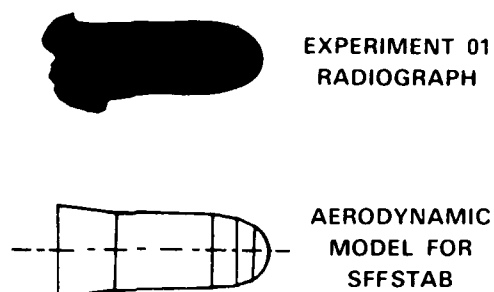
Figure 7  
 DERIVATIVE OF THE NORMAL FORCE COEFFICIENT FOR  
 SPHERICAL SEGMENTS (Reference [3])



**Figure 8**  
**DERIVATIVE OF THE NORMAL FORCE COEFFICIENT FOR CONE FRUSTUMS**  
**(Reference [3])**



**Figure 9**  
**APPROXIMATION OF LINER GEOMETRY BY SEGMENTS**



REQUIRED FRAGMENT SPIN RATE = 6940 (RAD/SEC) = 66280 (RPM)  
REQUIRED CHARGE (SFF) SPIN RATE = 404 (RAD/SEC) = 3860 (RPM)

**Figure 10**  
**"SFFSTAB" RESULTS FOR EXPERIMENTALLY**  
**OBSERVED FRAGMENT**



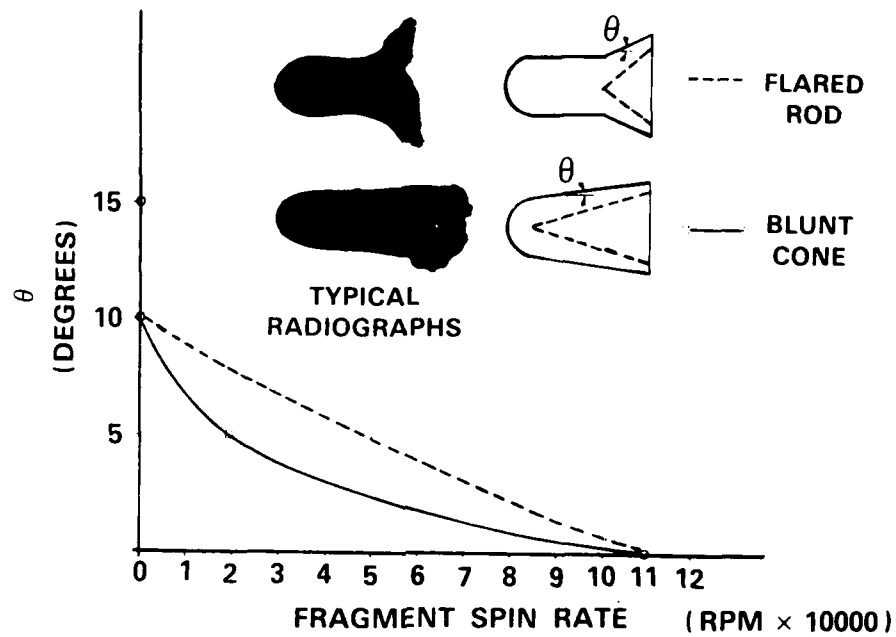


Figure 11  
FRAGMENT SPIN RATE REQUIRED FOR  
DYNAMIC STABILITY VS FLARE ANGLE  $\theta$

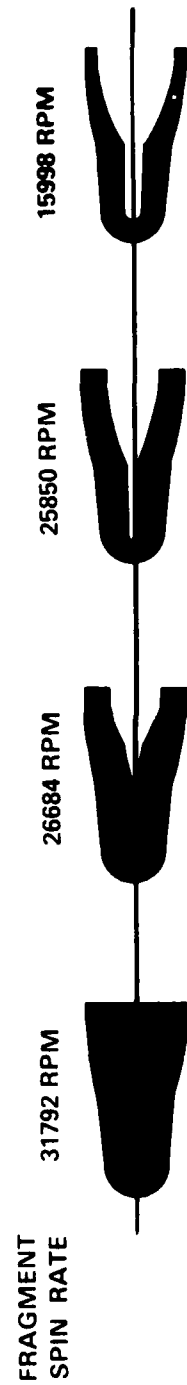


Figure 12  
SPIN RATE REQUIRED FOR DYNAMIC STABILITY OF  
FRAGMENTS WITH DIFFERENT INTERIOR PROFILES

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APPENDIX A - DATCOM METHOD

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DATCOM METHOD FOR HYPERSONIC FLOW

The DATCOM Method [3] uses the results of Newtonian impact theory. Design charts and equations are presented in Reference 3, for determining the aerodynamic characteristics at hypersonic speeds of projectile shapes composed of one or more cone frustums with or without a spherical nose. The coefficients required for gyroscopic and dynamic stability equations are given in this Appendix. The relevant coefficients are:

- i)  $C_{N_\alpha}$  : NORMAL-FORCE-CURVE SLOPE
- ii)  $C_{m_\alpha}$  : PITCHING MOMENT CURVE SLOPE
- iii)  $C_D$  : DRAG COEFFICIENT
- iv)  $C_{N_q}$  : PITCHING DERIVATIVE
- v)  $C_{m_q}$  : PITCHING DERIVATIVE
- vi)  $C_{m_{\ddot{\alpha}}}$  : BODY ACCELERATION DERIVATIVE

The information contained in this Appendix has been extracted from Reference 3.

i)  $C_{N_\alpha}$  : NORMAL-FORCE-CURVE SLOPE

The normal-force-curve slope of a body composed of one or more cone frustums with or without a spherical nose, based on the body base area, is given by

$$\frac{dC_N}{d\alpha} = C_{N_\alpha} = \sum_{n=1}^m (C_{N_\alpha})_n \left( \frac{d_n}{d_b} \right)^2 \quad (A.1)$$

To apply this equation the body is divided into  $m$  segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment a cone frustum. The normal-force-curve slope of a spherical nose, based on area, is obtained from Figure A-1. The normal-force-curve slope of a cone frustum, based on the base area of the specific segment, is obtained from Figure A-2. (Note that a cylinder is considered a cone frustum with  $\theta = 0$  and  $a/d = 1.0$ , and that  $C_{N_\alpha} = 0$  by Newtonian impact theory.) The ratio  $(d_n/d_b)^2$  refers the normal-force-curve slope to the base area of the configuration.

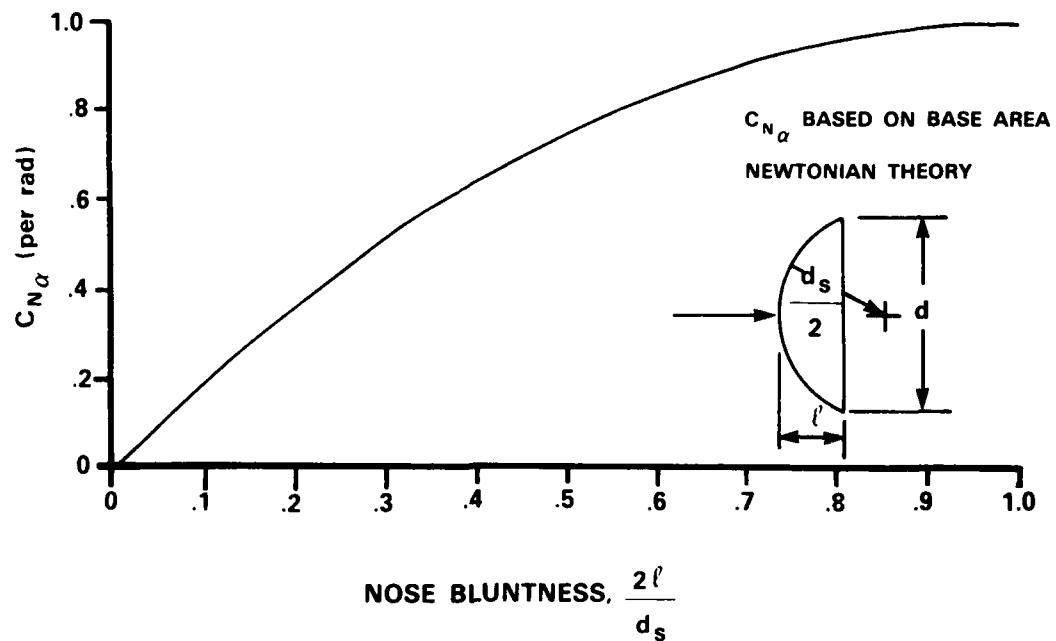


Figure A-1

NORMAL FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS  
(Reproduced from Figure 4.2.1.1-23 of Reference [3])

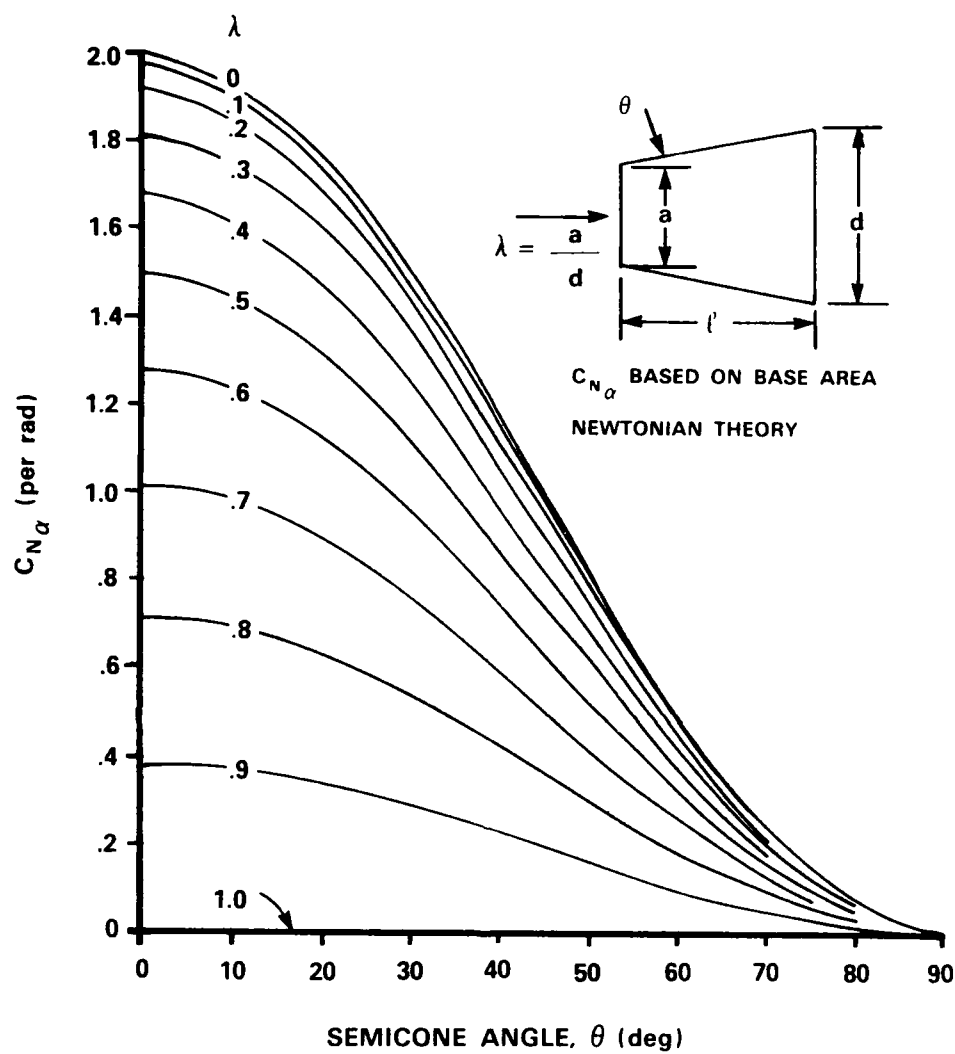


Figure A-2

## NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTUMS

(Reproduced from Figure 4.2.1.1-26 of Reference [3])

ii)  $C_{M_{\alpha}}$  : PITCHING MOMENT CURVE SLOPE

---

The procedure for computing the total pitching-moment-curve slope for a complex body is given in the following steps. The moment values for each individual segment of a multiple cone-frustum body with or without a spherical nose are referred to a moment axis at the front face of that particular segment, and are based on the product of the base area and base diameter of that particular segment.

Step 1: Compute  $C'_{m_{\alpha}}$  for each body segment about its own front face, using Figures A-3 and A-4.

Step 2: Transfer the individual moment slopes to a common reference axis by applying the following moment transfer equation to each body segment.

$$C_{m_{\alpha}} = C'_{m_{\alpha}} + \frac{n}{d} C_{N_{\alpha}} \text{ (per radian)} \quad (A.2)$$

where

$C_{N_{\alpha}}$  is the normal-force-curve slope of the individual cone-frustum or spherical nose segment, based on its own base area, from Figures A-2 and A-1, respectively.

$d$  is the base diameter of the individual cone-frustum or spherical nose segment.

$n$  is the distance from the front face of a given segment to the desired moment reference axis of the configuration, positive aft.



$C'_{m_\alpha}$  is the pitching-moment-curve slope of an individual segment from Figure A-3 for cone frustums and from Figure A-4 for spherical nose segments.  $C'_{m_\alpha}$  is based on the product of the base area and the base diameter of the individual segment.

$C_{m_\alpha}$  is the pitching-moment-curve slope of an individual segment based on the product of the base area and base diameter of the individual segment and referred to a common reference axis.

Step 3: The transferred pitching-moment-curve slopes of the individual body segments are then converted to a common basis by

$$C_{m_\alpha} = \sum_{n=1}^m (C_{m_\alpha})_n \left( \frac{d_n}{d_b} \right)^3 \quad (\text{per radian}) \quad (A.3)$$

where the subscript  $n$  refers to an individual segment of  $m$  segments, and  $C_{m_\alpha}$  is referred to a common reference axis and is based on the product of the area and diameter of the base of the configuration  $S_b d_b$ .

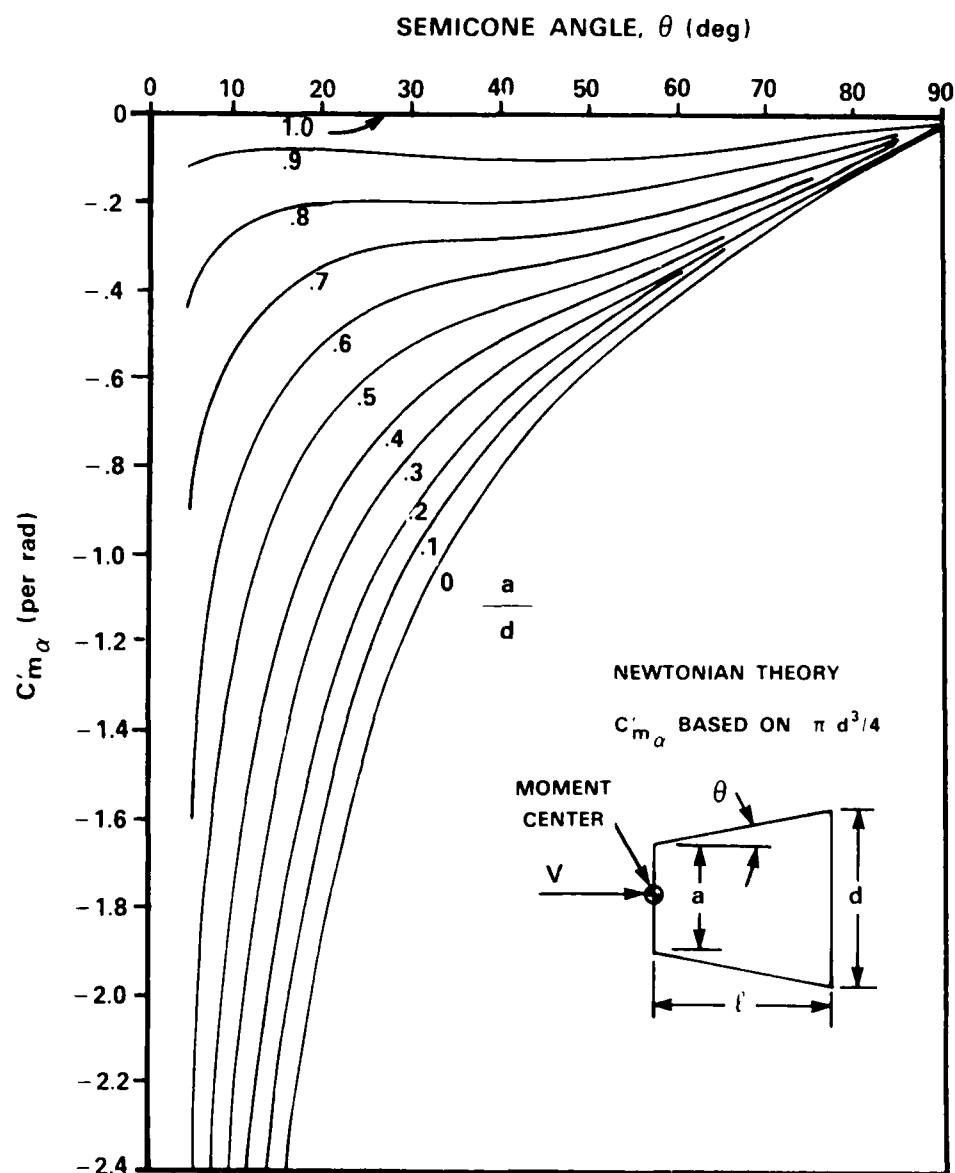


Figure A-3

 $C'_{m_\alpha}$  FOR CONE FRUSTUMS

(Reproduced from Figure 4.2.2.1-25a of Reference [3])

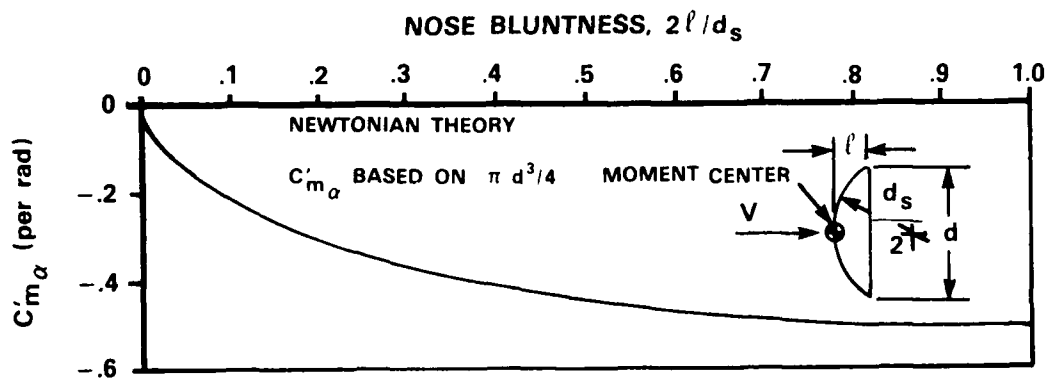


Figure A-4

$C'_{m_\alpha}$  FOR SPHERICAL SEGMENTS

(Reproduced from Figure 4.2.2.1-25b of Reference [3])

iii)  $C_D$ : DRAG COEFFICIENT

The zero-lift drag (based on the maximum frontal area) of a body composed of one or more cone frustums with or without a spherical nose is estimated by adding the pressure-drag coefficient of each segment to the body skin-friction drag coefficient.

$$C_{D_o} = C_{D_f} + \sum_{n=1}^m C_{D_{Pn}} \left( \frac{d_n}{d_{\max}} \right)^2 \quad (A.4)$$

The procedure to be followed in evaluating this equation is as follows:

Step 1: Divide the body into  $m$  segments, the first segment being either a spherical nose or a cone frustum, and each succeeding segment a cone frustum. The pressure-drag coefficient for a spherical nose or cone frustum is obtained from Figures A-5 and A-6, respectively. The pressure-drag coefficients for the remainder of the segments are obtained from Figure A-7. The pressure-drag coefficients are based on the base area of the specific segment. The ratio  $(d_n/d_{\max})^2$  refers the pressure-drag coefficients to the maximum body frontal area.

Step 2: Obtain the body skin-friction drag coefficient by

$$C_{D_f} = 1.02 C_{f_{inc}} \frac{C_{f_c} S_S}{C_f S_B} \quad (A.5)$$

where

$C_{f_{inc}}$  is the incompressible ( $M = 0$ ) turbulent, flat-plate skin-friction coefficient, including roughness effects, as a function of Reynolds number based on the total length of the body  $\ell_B$ . This value is obtained from Figure A-8.

$\ell$  is the reference length in inches.

$k$  is the surface-roughness height in inches; it depends upon surface finish. Representative values for this parameter can be obtained from Table A-1.

The ratio  $\ell/k$  is computed and Figure A-9 is used to obtain the cutoff Reynolds number. If the cutoff Reynolds number is greater than the computed Reynolds number for the specific configuration, the value of  $C_f$  is obtained from Figure A-8 at the computed Reynolds number. If the cutoff Reynolds number is less than the computed Reynolds number, the value of  $C_f$  is obtained from Figure A-8 at the cutoff Reynolds number.

$\frac{C_{f_c}}{C_f}$  is the ratio of compressible to incompressible skin-friction coefficient obtained from Figure A-10.

$\frac{S_S}{S_B}$  is the ratio of the body wetted area to maximum body frontal area.

If this method is applied at Mach numbers low enough so that the base drag is significant, the base drag should be added to the results obtained. Unfortunately, the only base-drag coefficient results available which are compatible with the Newtonian-theory results (restricted to bodies with forward facing slopes or cylinders, in which case the Newtonian results are equal to zero) are those for cylindrical afterbodies. The pressure-drag coefficient for cylindrical afterbodies is presented in Figure A-11 for  $M < 10$ .

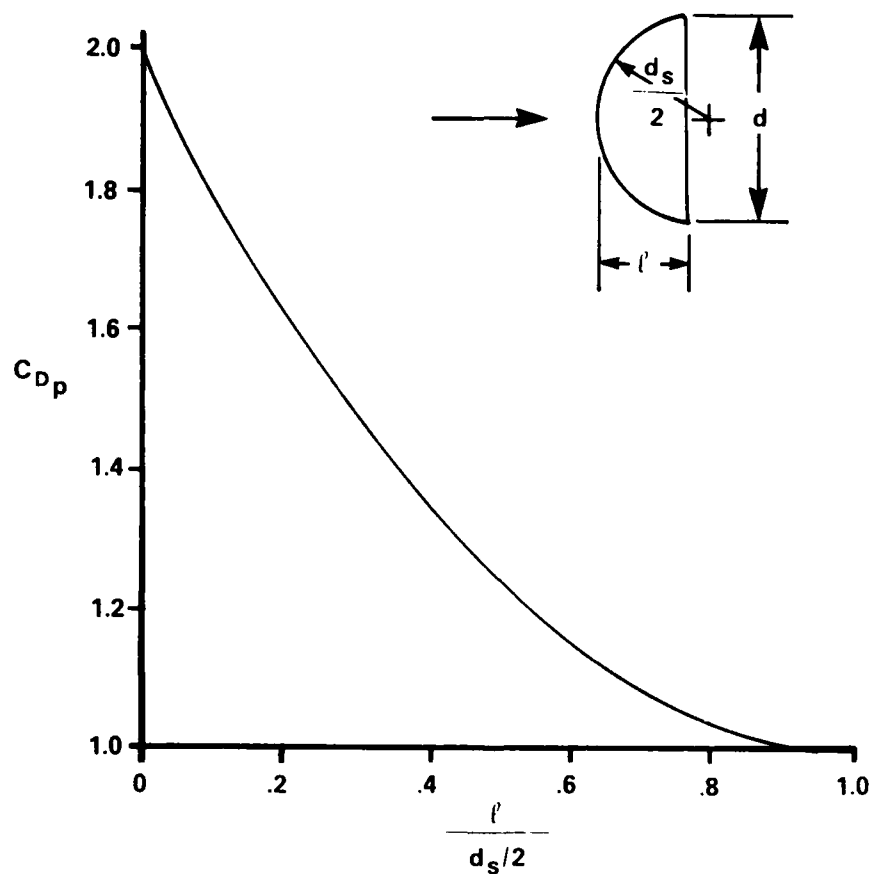


Figure A-5

**NEWTONIAN DRAG COEFFICIENT FOR SPHERICAL SEGMENTS  
REFERRED TO BASE AREA OF SEGMENT**

(Reproduced from Figure 4.2.3.1-66 of Reference [3])

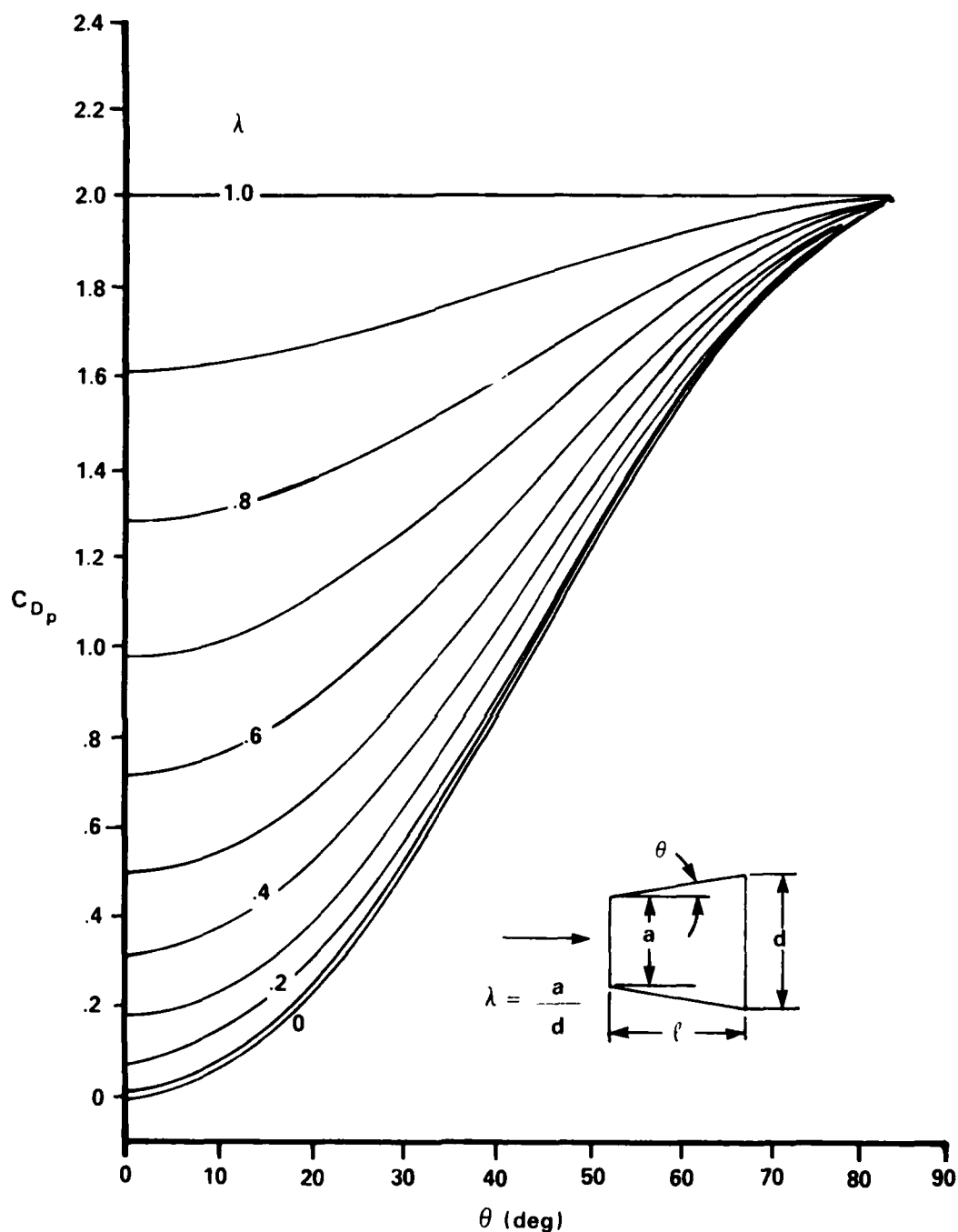


Figure A-6

DRAG COEFFICIENT FOR A CONE FRUSTUM CALCULATED FROM  
NEWTONIAN THEORY. THE GEOMETRIC PARAMETERS ARE

$$\text{RELATED BY THE EQUATION } \tan \theta = \frac{1 - \lambda}{2(\ell/d)}$$

(Reproduced from Figure 3 of Reference [6])



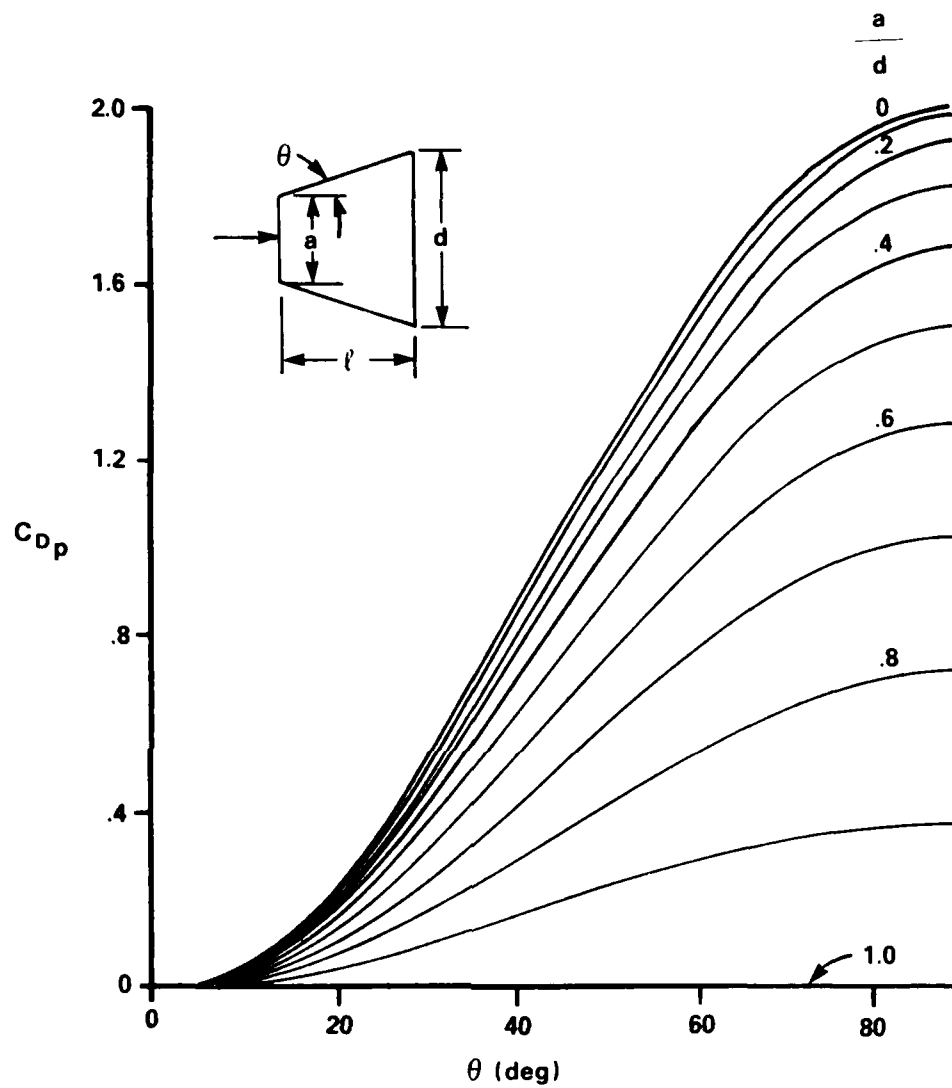


Figure A-7

DRAG-FORCE COEFFICIENT DUE ONLY TO THE INCLINED SIDES  
OF A CONE FRUSTUM CALCULATED BY NEWTONIAN THEORY.

$C_D$  IS BASED ON BODY BASE AREA  $S_b$ .

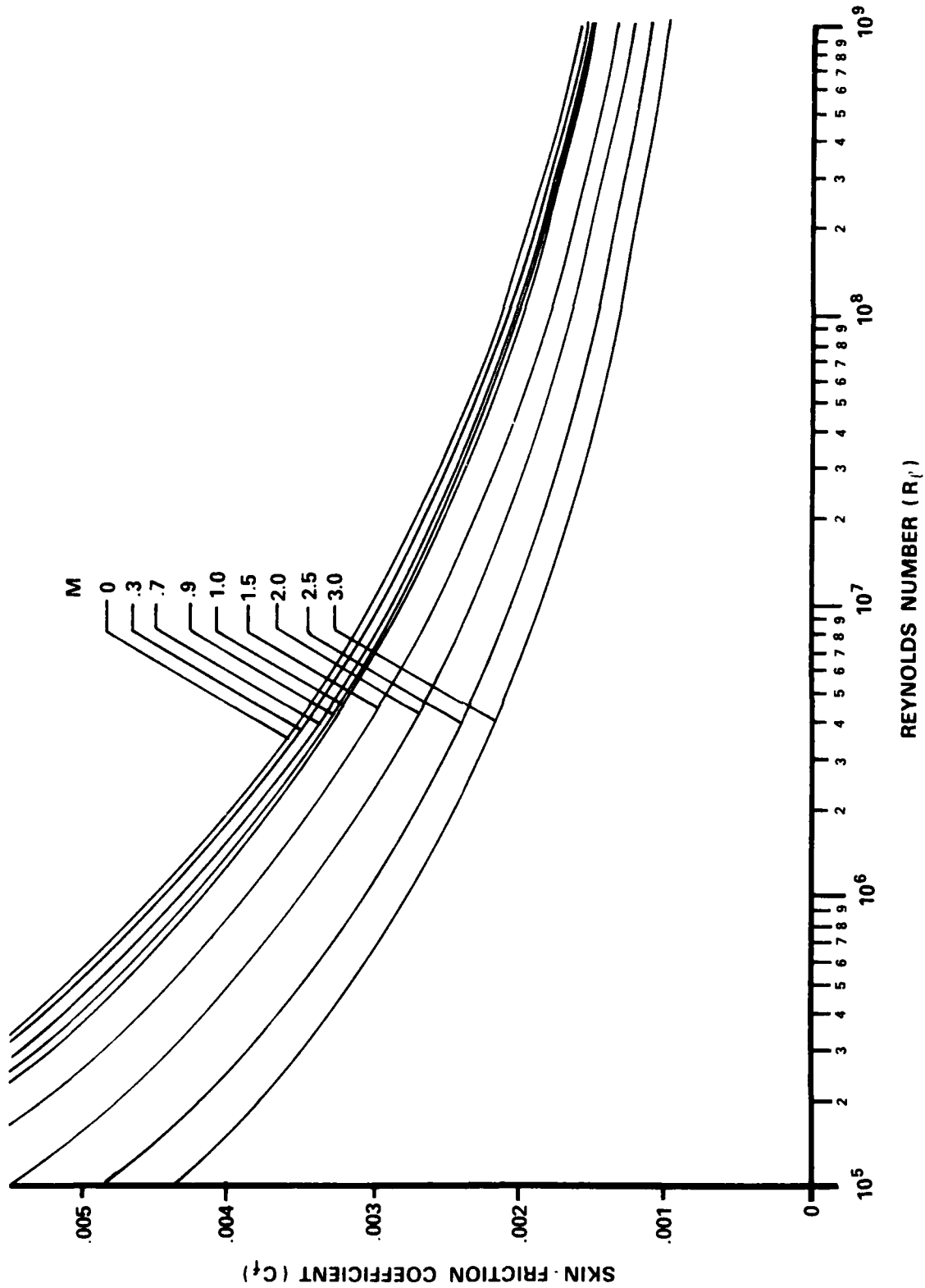
REYNOLDS NUMBER ( $Re$ )

Figure A-8

TURBULENT MEAN SKIN-FRICTION COEFFICIENT ON AN INSULATED FLAT PLATE  
(Reproduced from Figure 4.1.5.1-26 of Reference [3])

**Table A-1**  
**REPRESENTATIVE VALUES OF SURFACE-ROUGHNESS HEIGHT**  
**(Reproduced from Table 4.1.5.1-A of Reference [3])**

TYPE OF SURFACE	EQUIVALENT SAND ROUGHNESS k (inches)
Aerodynamically Smooth	0
Polished Metal or Wood	$0.02 - 0.08 \times 10^{-3}$
Natural Sheet Metal	$0.16 \times 10^{-3}$
Smooth Matte Paint, Carefully Applied	$0.25 \times 10^{-3}$
Standard Camouflage Paint, Average Application	$0.40 \times 10^{-3}$
Camouflage Paint, Mass-Production Spray	$1.20 \times 10^{-3}$
Dip-Galvanized Metal Surfaces	$6 \times 10^{-3}$
Natural Surface of Cast Iron	$10 \times 10^{-3}$

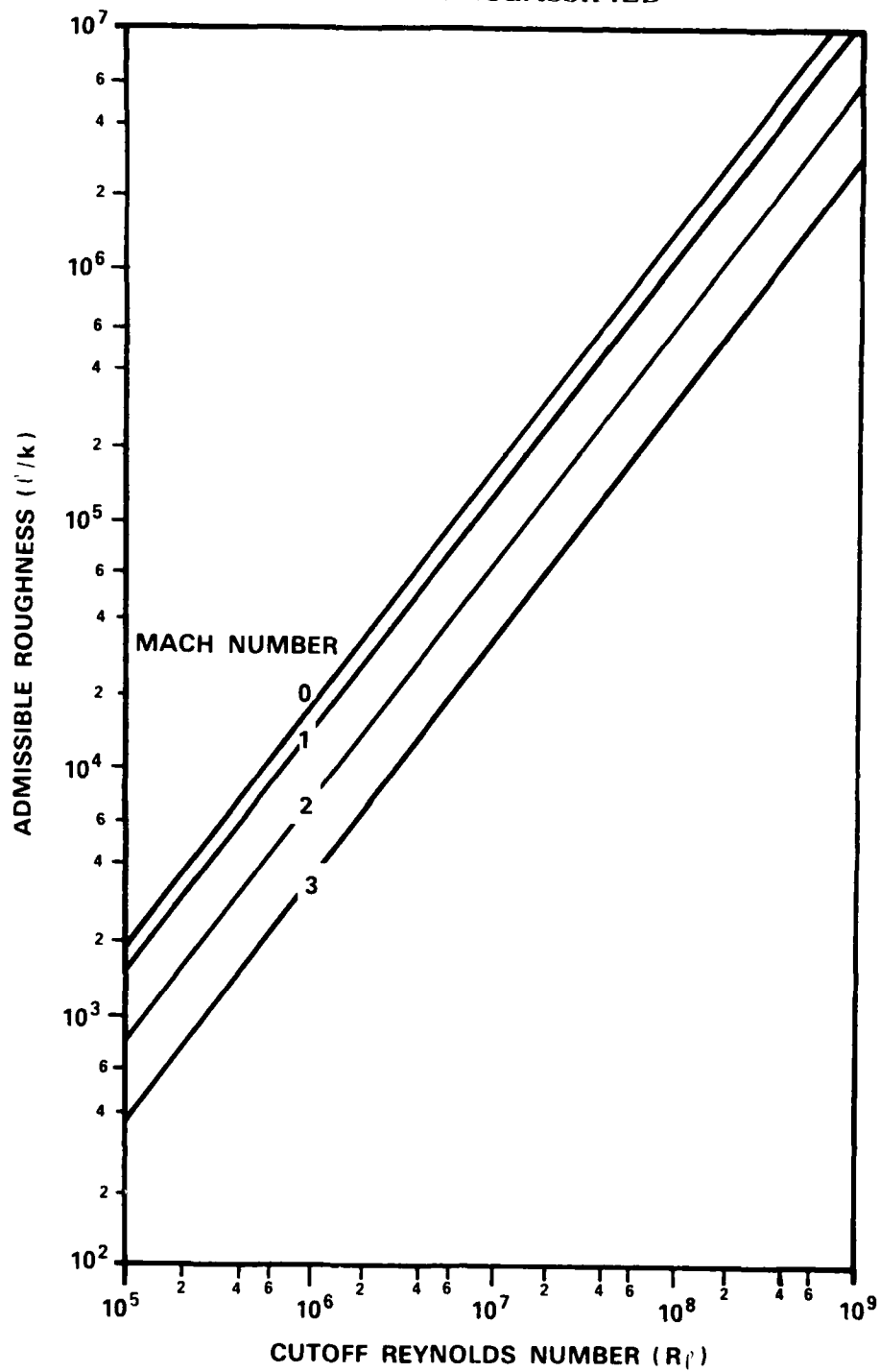


Figure A-9

CUTOFF REYNOLDS NUMBER

(Reproduced from Figure 4.1.5.1-27 of Reference [3])

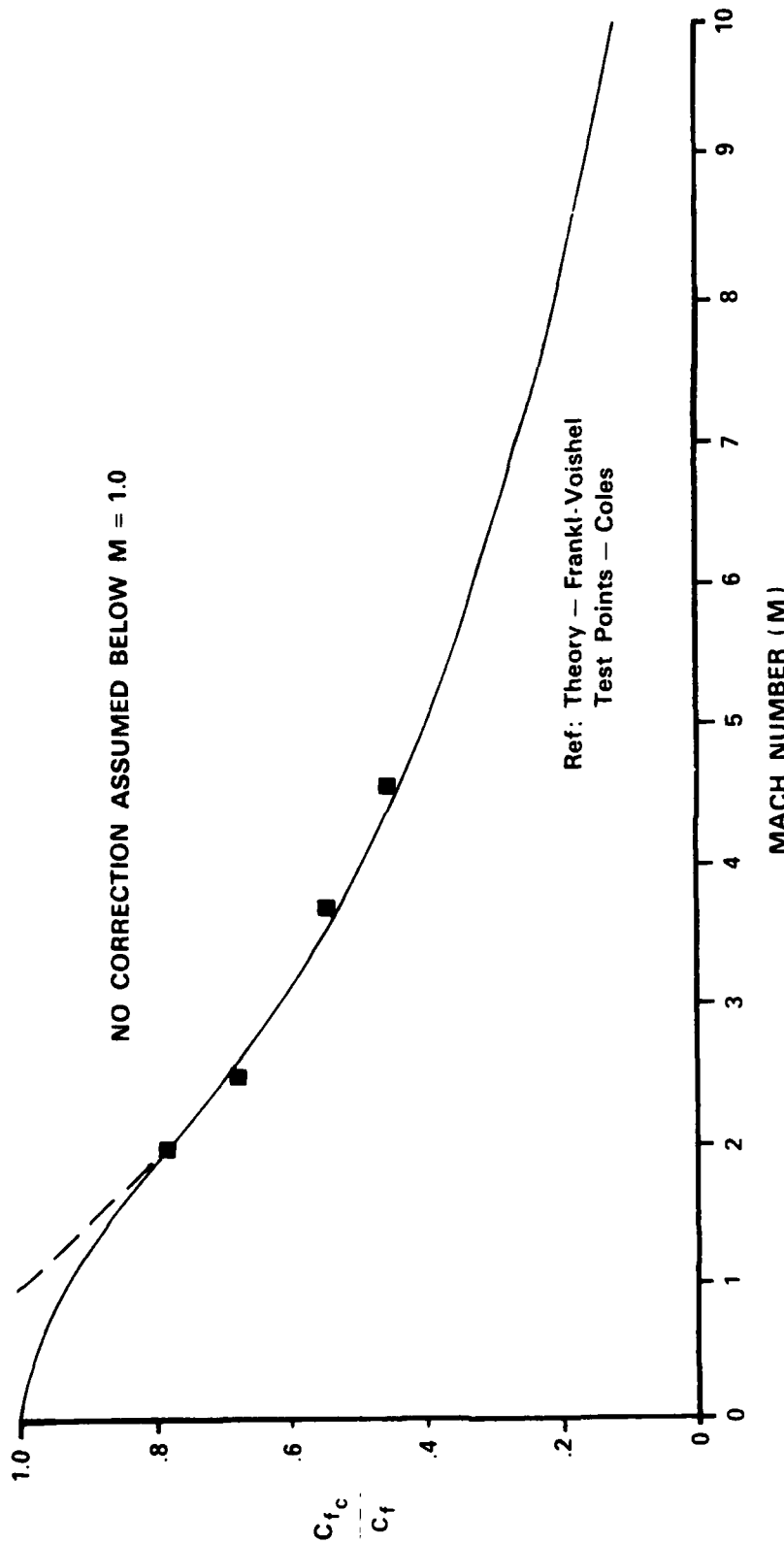


Figure A-10

# COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION (ZERO HEAT TRANSFER)

(Adapted from Figure 4.2.3.1-68 of Reference [3])

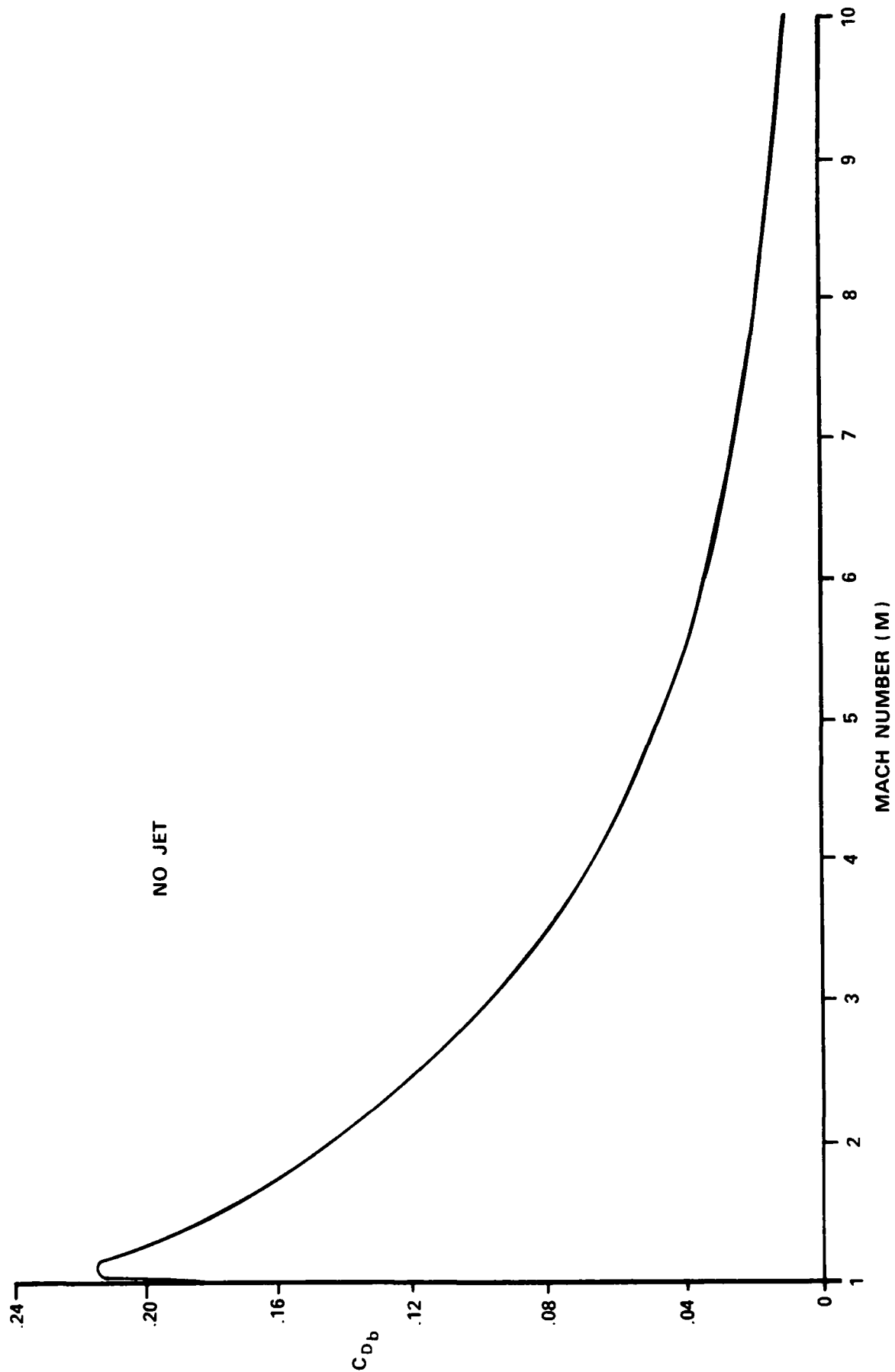


Figure A-11

BASE DRAG COEFFICIENT FOR BODIES OF REVOLUTION  
WITH NO BOATTAIL

(Adapted from Figure 4.2.3.1-60 of Reference [3])

iv)  $C_{N_q}$  : PITCHING DERIVATIVE

Charts based on simple Newtonian theory, are presented for determining  $C_{N_q}$  of spherical segments and cone frustums at small angles of attack.

The coefficients of these charts are referred to the body base area and base diameter and to a moment center at the forward face of the segment. By proper use of the data presented, the total  $C_{N_q}$  may be determined for bodies composed of multiple cone frustums with or without spherically blunted noses.

The Newtonian value of the derivative  $C_{N_q}$  for a complex body is obtained as follows:

Step 1: Compute  $C'_{N_q}$  for each body segment about its front face using Figures A-12 and A-13.

Step 2: Transfer the individual derivatives  $C'_{N_q}$  to a common reference axis by applying the following transfer equation to each body segment

$$C_{N_q} = C'_{N_q} - 2 \left( \frac{n}{d} \right) C_{N_\alpha} \quad (A.6)$$

where

$C_{N_\alpha}$  is the normal-force-curve slope for each segment based on individual base areas.

$C'_{N_q}$  is the pitching derivative for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment, from Figures A-12 and A-13.

$n$  is the distance from the face of a given frustum to the desired moment reference axis of the configuration, positive aft.

$d$  is the base diameter of a given frustum.

Step 3: The transferred derivatives of the individual body segments are converted to a common reference area and diameter and added. The total derivative is given by

$$C_{N_q} = \sum_{n=1}^m (C_{N_q})_n \left( \frac{d_n}{d_b} \right)^3 \quad (A.7)$$



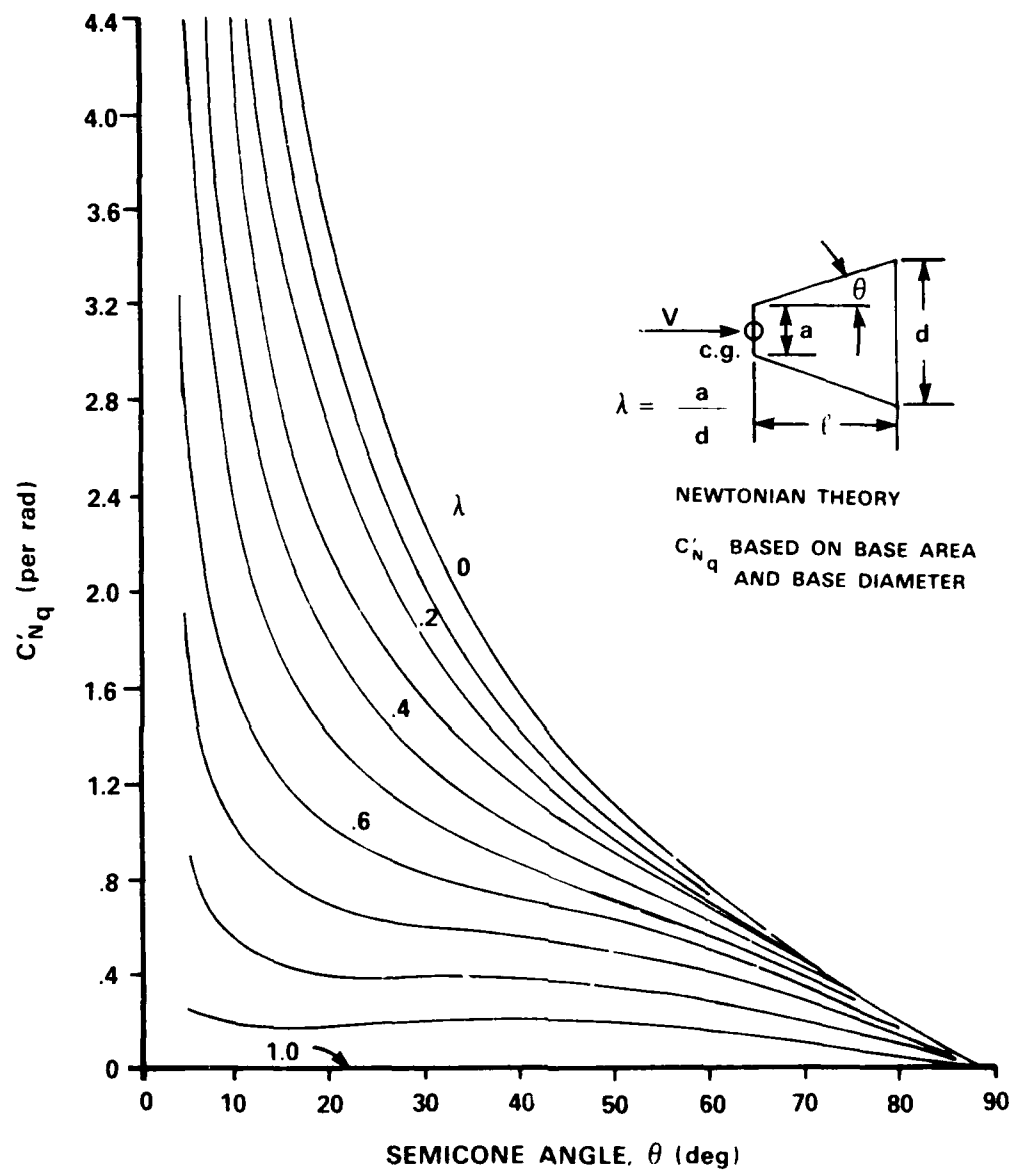


Figure A-12

PITCHING DERIVATIVE  $C'_{Nq}$  FOR CONE FRUSTUMS  
 (Reproduced from Figure 7.2.1.1-9a of Reference [3])

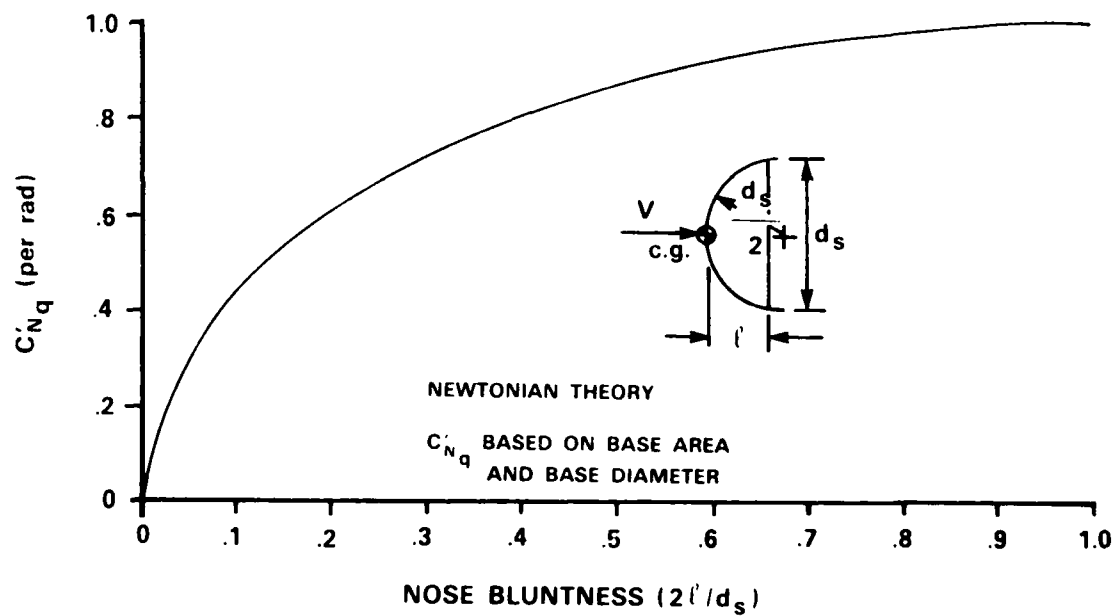


Figure A-13

PITCHING DERIVATIVE  $C'_{Nq}$  FOR SPHERICAL SEGMENTS  
 (Reproduced from Figure 7.2.1.1-9b of Reference [3])

v)  $C_{m_q}$  : PITCHING DERIVATIVE

Charts based on simple Newtonian theory are presented for determining  $C_{m_q}$  of spherical segments and cone frustums at small angles of attack. The coefficients of these charts are referred to the base area and the square of the base diameter and to a moment center at the forward face of the segment. By proper use of the data presented, the total  $C_{m_q}$  may be determined for bodies composed of multiple cone frustums with or without spherically blunted noses.

The Newtonian value of the stability derivative  $C_{m_q}$  for a complex body is obtained as follows:

Step 1: Compute  $C_{m_q}'$  for each body segment about its own front face using Figures A-14 and A-16 if the body has a spherically blunted nose, and Figures A-14 and A-15 if the body nose is a cone frustum.

Step 2: Transfer the individual derivatives  $C_{m_q}'$  to a common moment center by applying the following axis transfer equation to each body segment:

$$C_{m_q} = C_{m_q}' - 2 \frac{n}{d} C_{m_\alpha}' + \frac{n}{d} C_{N_q} - 2 \left( \frac{n}{d} \right)^2 C_{N_\alpha} \quad (A.8)$$

where

$C_{N_\alpha}$  is the normal-force-curve slope for each segment based on individual base areas.

$C'_{Nq}$  is the pitching derivative for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment.

$C'_{m\alpha}$  is the pitching-moment-curve slope for each segment based on individual base areas and base diameters and referred to a moment center at the forward face of the segment.

$C'_{mq}$  is the pitching derivative for each body segment based on individual base areas and the square of base diameters and referred to a moment center at the forward face of the segment. If a complex body consists of combinations of cone frustums, the derivative for the first frustum must be obtained from Figure A-15, which accounts for the front face being exposed to the air stream. If the body has a spherically blunted nose, the derivative of the nose is obtained from Figure A-16. For subsequent frustums the derivatives are obtained from Figure A-14.

Step 3: The transferred derivatives of the individual body segments are added after being converted to a common reference area and squared diameter. The total derivative of the individual body segments is given by

$$C_{mq} = \sum_{n=1}^m (C_{mq})_n \left( \frac{d_n}{d_b} \right)^4 \quad (A.9)$$

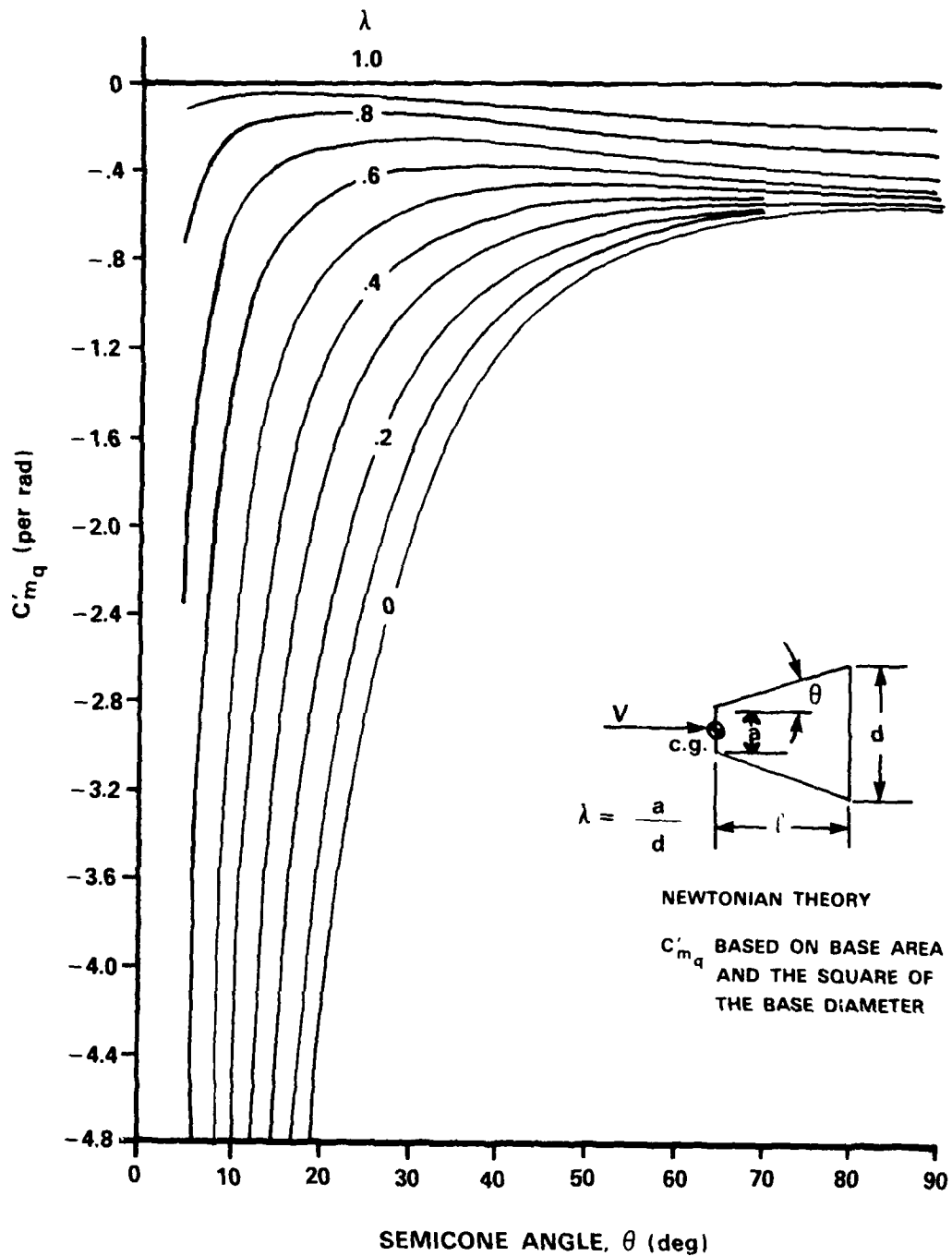


Figure A-14

PITCHING DERIVATIVE  $C'_{mq}$  DUE TO INCLINED SIDES OF CONE FRUSTUMS  
 (Reproduced from Figure 7.2.1.2-12 of Reference [3])

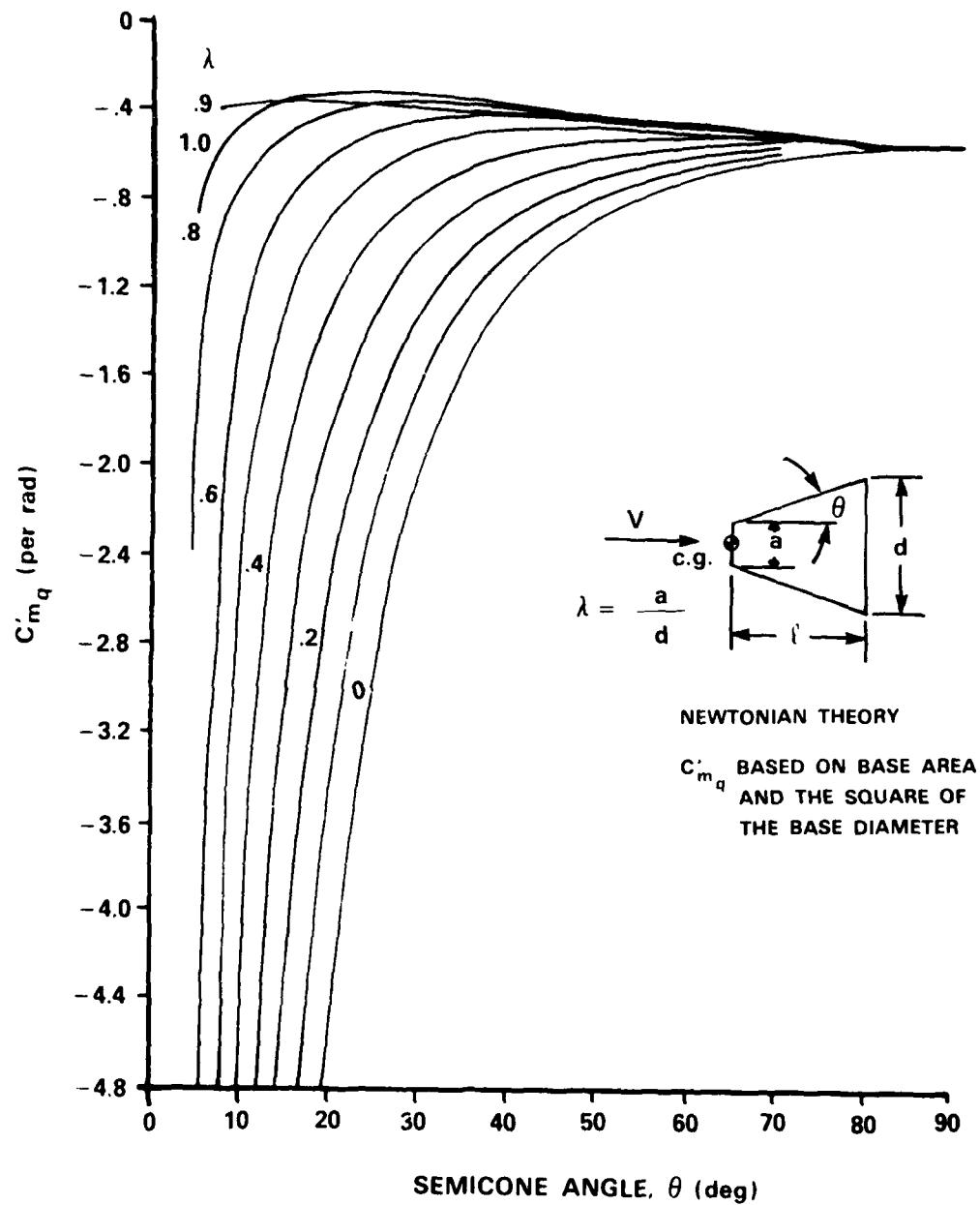


Figure A-15

PITCHING DERIVATIVE  $C'_{m_q}$  FOR CONE FRUSTUMS  
 (Reproduced from Figure 7.2.1.2-13a of Reference [3])

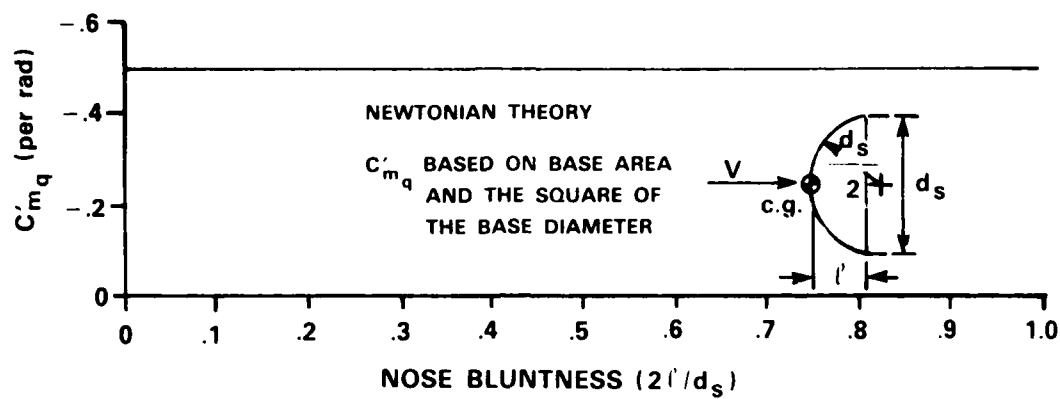


Figure A-16

PITCHING DERIVATIVE  $C'_{m_q}$  FOR SPHERICAL SEGMENTS  
 (Reproduced from Figure 7.2.1.2-13b of Reference [3])

vi)  $C_{m_\alpha}$ : BODY ACCELERATION DERIVATIVE

The body contribution to the derivative  $C_{m_\alpha}$  in the hypersonic speed range is equal to zero when determined by the Newtonian Impact Theory.

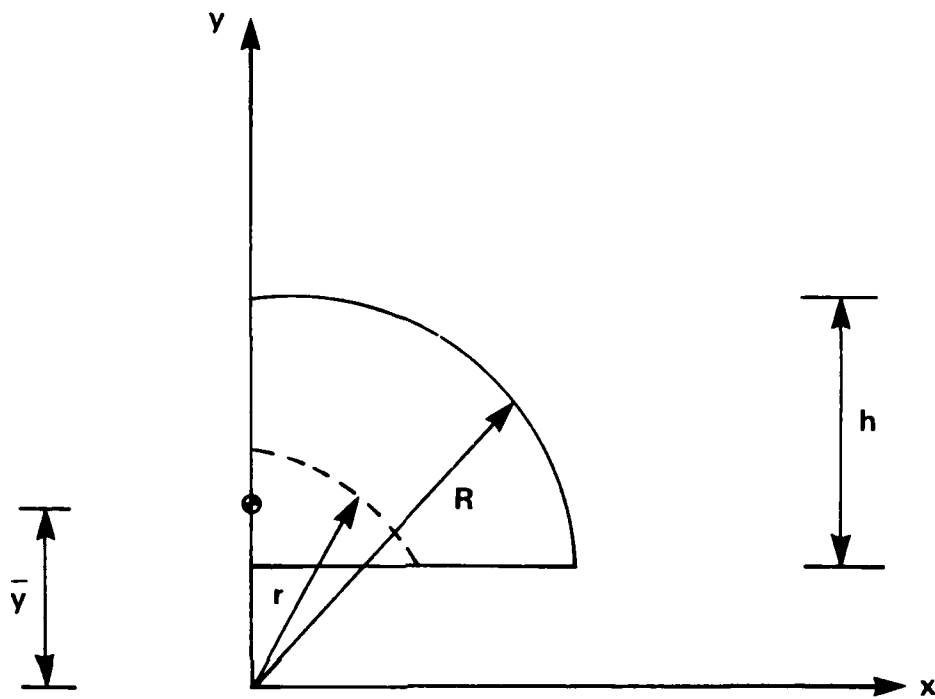


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APPENDIX B - SEGMENT PROPERTIES

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## HOLLOW SPHERICAL SEGMENT



$r$  = INNER RADIUS OF SPHERICAL SEGMENT

$R$  = OUTER RADIUS OF SPHERICAL SEGMENT

$h$  = HEIGHT OF SPHERICAL SEGMENT

$\bar{y}$  = CENTROID OF SPHERICAL SEGMENT

PROPERTIES OF A SPHERICAL SEGMENTVolume

$$V = \pi \left[ Rr^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3} \right]$$

Centroid

$$\bar{y} = \frac{3 \left[ (R^2 - r^2)(4hR - 2h^2) - (R^2 - r^2)^2 \right]}{4 \left[ 3h(R^2 - r^2) + 3Rr^2 - R^3 - 2r^3 \right]}$$

Axial Moment of Inertia (Taken about Y-axis)

$$I_A = \frac{M \left[ \frac{8}{15} (R^5 - r^5) + (R-h)(r^4 - R^4) + \frac{2}{3} (R-h)^3 (R^2 - r^2) \right]}{2 \left[ Rr^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3} \right]}$$

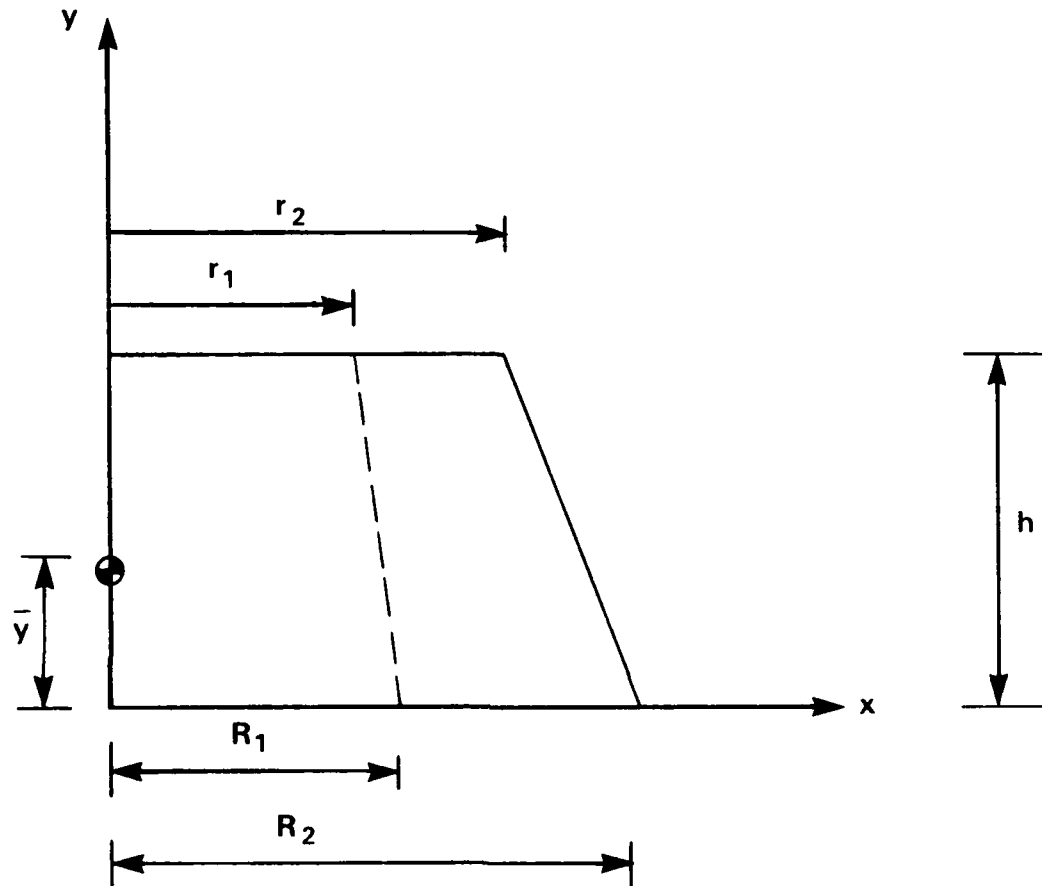
Where M = Mass = Density  $\times$  Volume

TRANSVERSE MOMENT OF INERTIA

(Taken Parallel to X-axis and Through the Centroid)

$$\begin{aligned}
 I_T &= \frac{M}{\left[ Rr^2 + hR^2 - hr^2 - \frac{R^3}{3} - \frac{2r^3}{3} \right]} \\
 &+ \left[ \frac{1}{4} (R^4 - r^4) (r - R + h) + (R^2 - r^2) \left\{ \frac{1}{6} (r^3 - (r-h)^3) \right. \right. \\
 &\quad \left. \left. + \bar{y}^2 (r - R + h) - \bar{y} (r^2 - (R-h)^2) \right\} \right. \\
 &\quad \left. + \frac{R^4}{4} (R-r) + R^2 \left\{ \frac{1}{6} (R^3 - r^3) + \bar{y}^2 (R-r) - \bar{y} (R^2 - r^2) \right\} \right. \\
 &\quad \left. - \frac{3}{20} (R^5 - r^5) + \frac{\bar{y}}{2} (R^4 - r^4) - \frac{\bar{y}^2}{3} (R^3 - r^3) \right]
 \end{aligned}$$

## HOLLOW TRUNCATED CONE



$r_1$  = INNER RADIUS AT SMALL END OF TRUNCATED CONE

$r_2$  = OUTER RADIUS AT SMALL END OF TRUNCATED CONE

$R_1$  = INNER RADIUS AT LARGE END OF TRUNCATED CONE

$R_2$  = OUTER RADIUS AT LARGE END OF TRUNCATED CONE

$h$  = SEGMENT HEIGHT

$\bar{y}$  = CENTROID

PROPERTIES OF A HOLLOW TRUNCATED CONEVolume

$$V = \frac{\pi h}{3} [R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1]$$

Centroid

$$\bar{y} = \frac{h}{4} \frac{[R_2^2 - R_1^2 + 3r_2^2 - 3r_1^2 + 2R_2 r_2 - 2R_1 r_1]}{[R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1]}$$

Axial Moment of Inertia (Taken about Y-axis)

$$I_A = \frac{3M}{10} [(R_2^4 + R_2^3 r_2 + R_2^2 r_2^2 + R_2 r_2^3 + r_2^4) - (R_1^4 + R_1^3 r_1 + R_1^2 r_1^2 + R_1 r_1^3 + r_1^4)] / [R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1]$$

Where M = Mass = Density × Volume

TRANSVERSE MOMENT OF INERTIA

(Taken Parallel to X-axis and Through the Centroid)

$$\begin{aligned}
I_T = & \left[ \frac{3M}{4} \left\{ R_2^4 - 2R_2^3 (R_2 - r_2) + 2R_2^2 (R_2 - r_2)^2 - R_2 (R_2 - r_2)^3 + \frac{(R_2 - r_2)^4}{5} \right. \right. \\
& - R_1^4 + 2R_1^3 (R_1 - r_1) - 2R_1^2 (R_1 - r_1)^2 + R_1 (R_1 - r_1)^3 - \left. \frac{(R_1 - r_1)^4}{5} \right\} \\
& + 3M \left( h^2 \left\{ \frac{R_2^2}{3} + \frac{(R_2 - r_2)^2}{5} - R_2 \frac{(R_2 - r_2)}{2} - \frac{R_1^2}{3} - \frac{(R_1 - r_1)^2}{5} + R_1 \frac{(R_1 - r_1)}{2} \right\} \right. \\
& + \bar{y}^2 \left\{ R_2^2 + \frac{(R_2 - r_2)^2}{3} - R_2 (R_2 - r_2) - R_1^2 - \frac{(R_1 - r_1)^2}{3} + R_1 (R_1 - r_1) \right\} \\
& + \bar{y}h \left\{ -R_2^2 - \frac{(R_2 - r_2)^2}{2} + 4R_2 \frac{(R_2 - r_2)}{3} + R_1^2 + \frac{(R_1 - r_1)^2}{2} - 4R_1 \frac{(R_1 - r_1)}{3} \right\} \left. \right] \\
& / [R_2^2 - R_1^2 + r_2^2 - r_1^2 + R_2 r_2 - R_1 r_1]
\end{aligned}$$

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APPENDIX C - FLOW CHART AND FORTRAN LISTING OF SFFSTAB

UNCLASSIFIED



## SFFSTAB: FLOWCHART

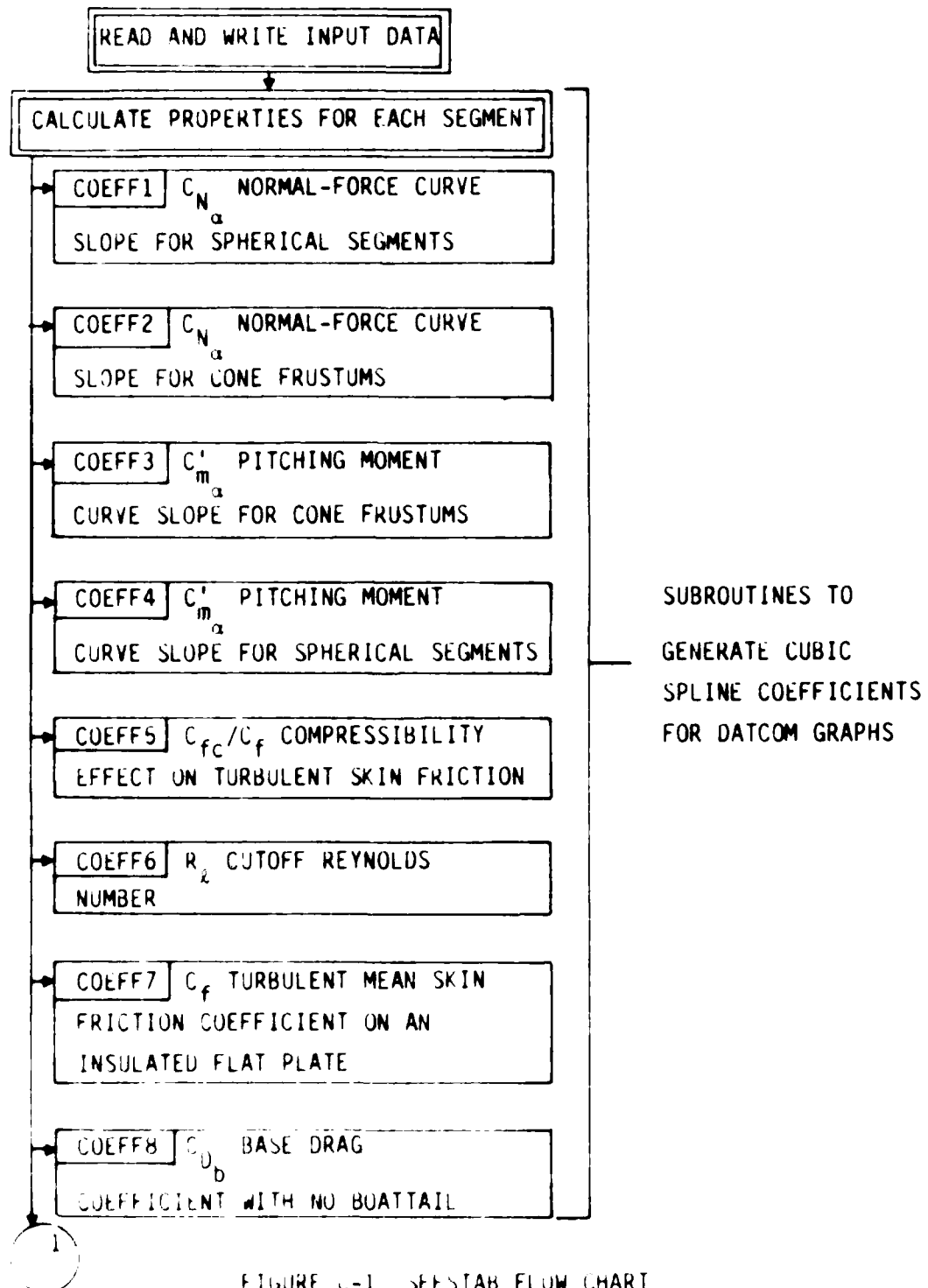


FIGURE C-1 SFFSTAB FLOW CHART

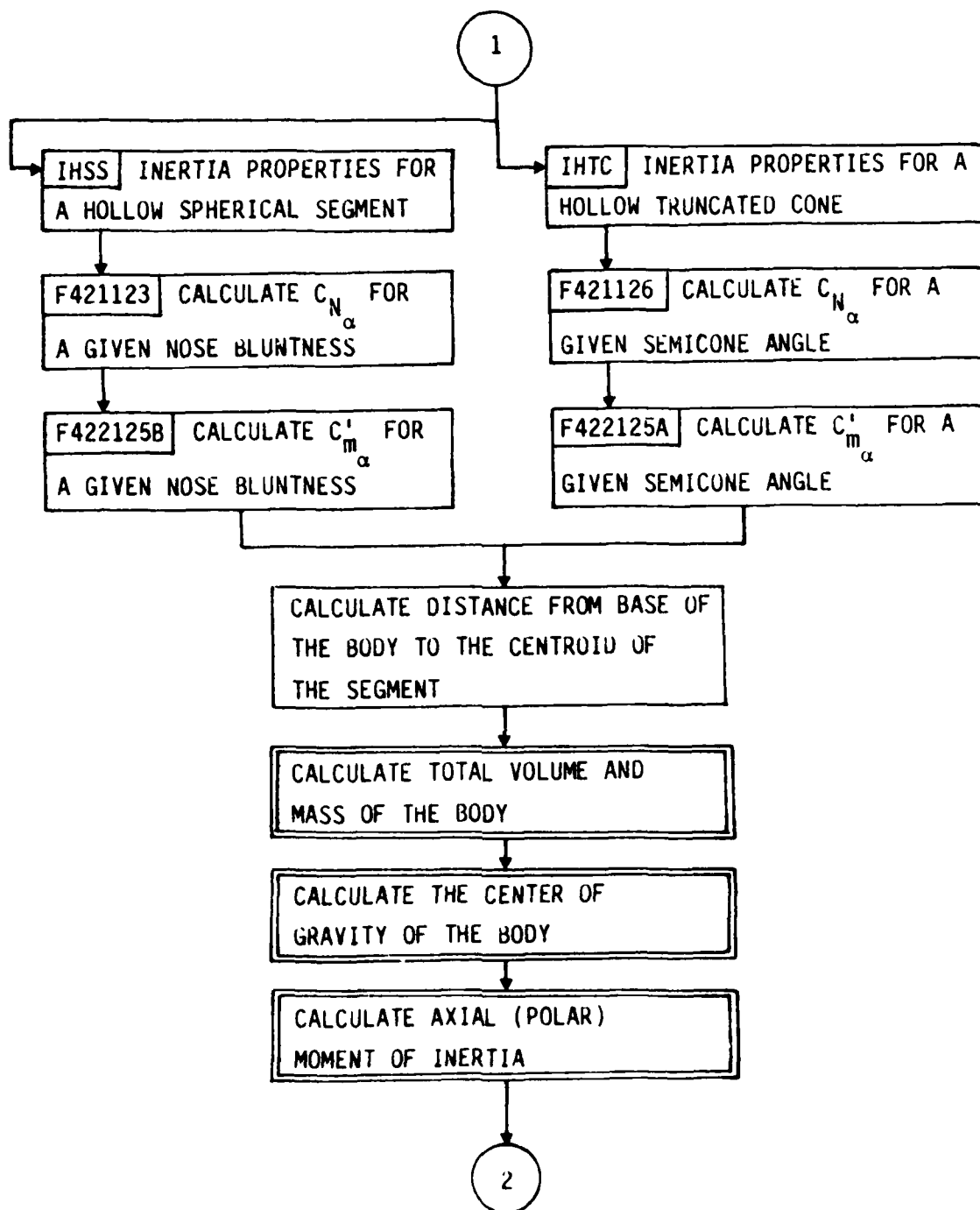


FIGURE C-2 SFFSTAB FLOWCHART CONT'D

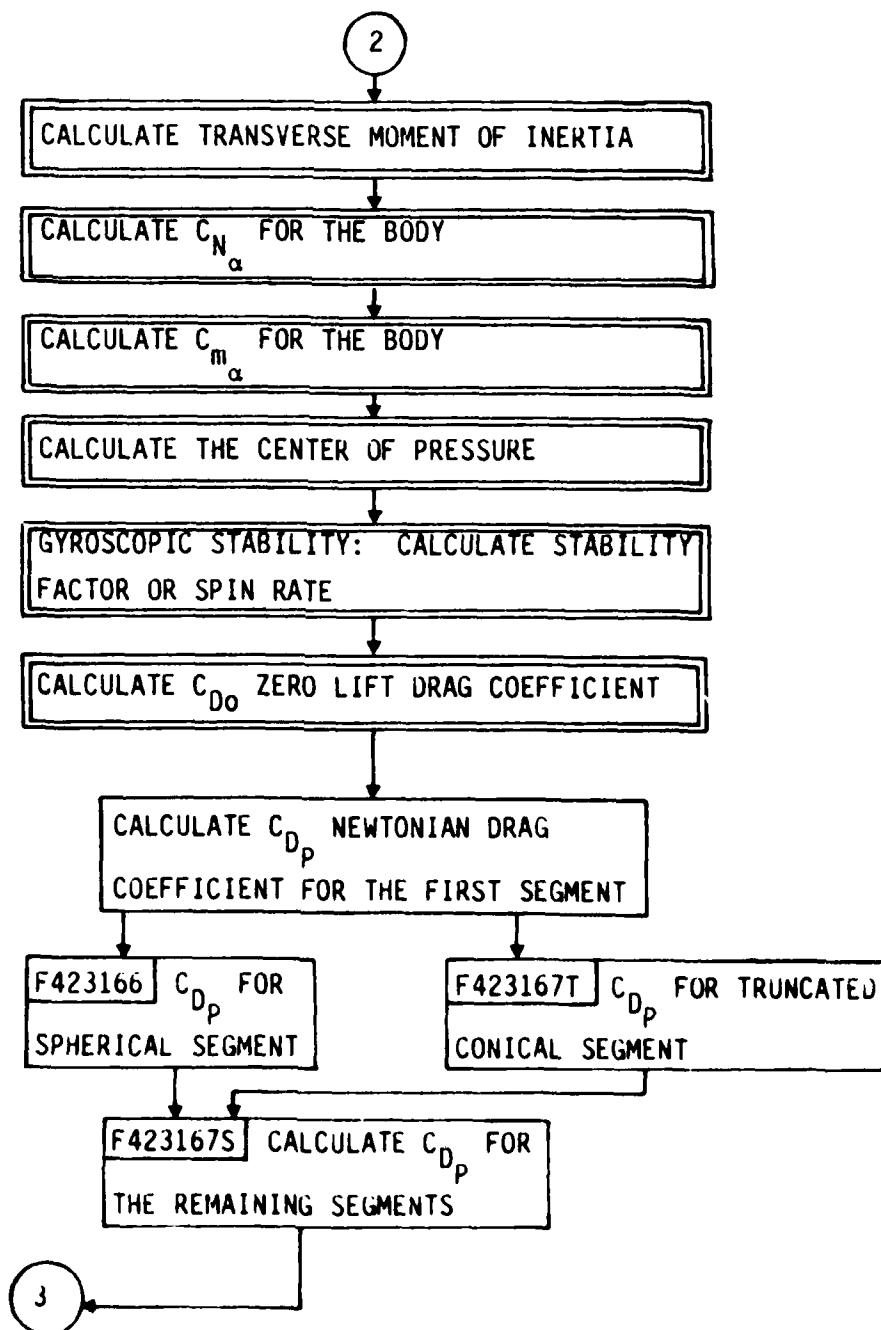


FIGURE C-3 SFESTAB FLOW CHART CONT'D

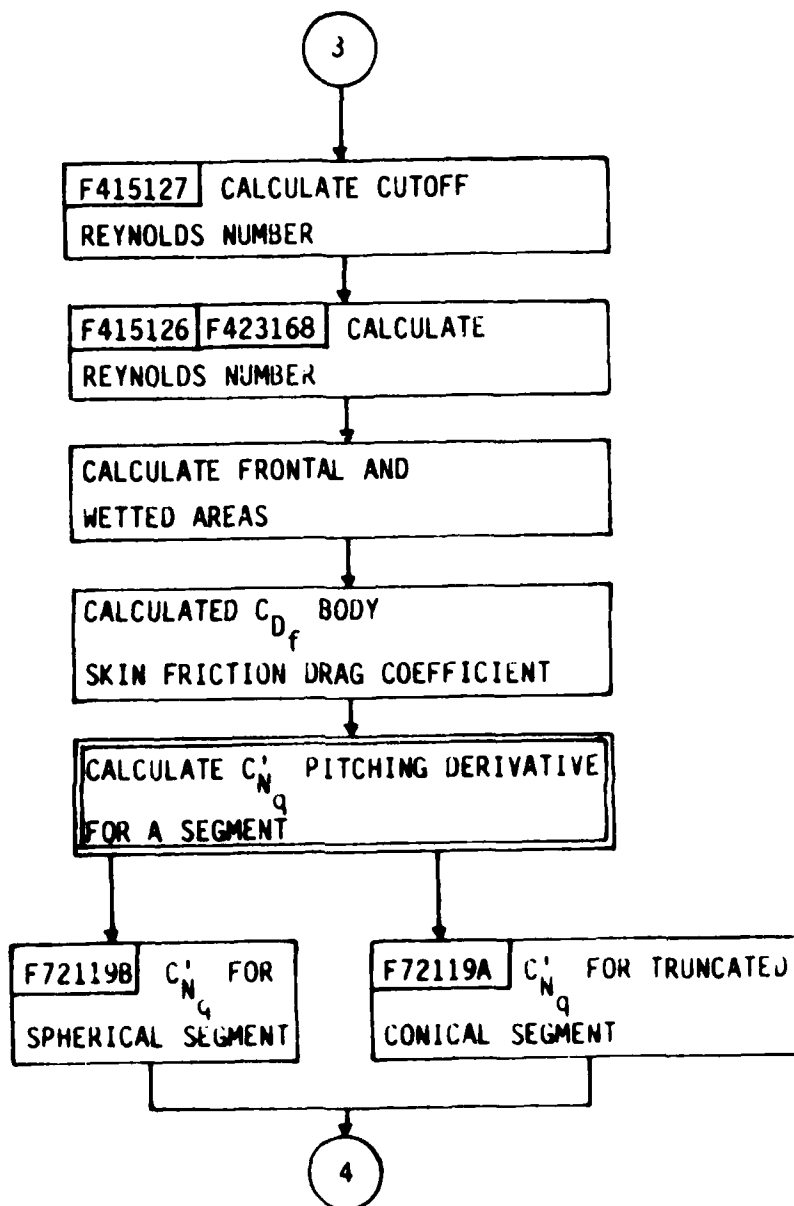


FIGURE C-4 SFFSTAB FLOWCHART CONT'D

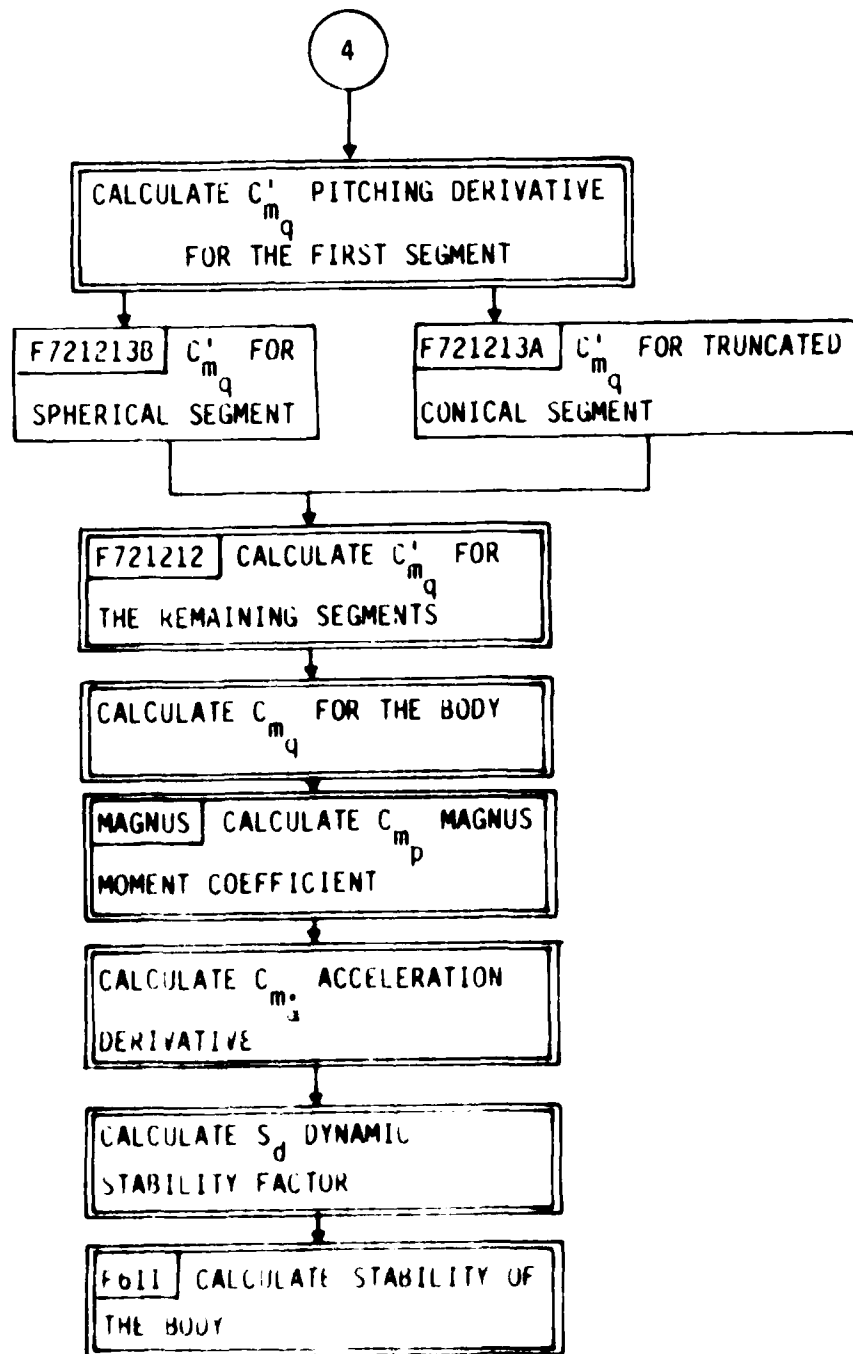


FIGURE C-5 SFESTAB FLOW CHART CONT'D

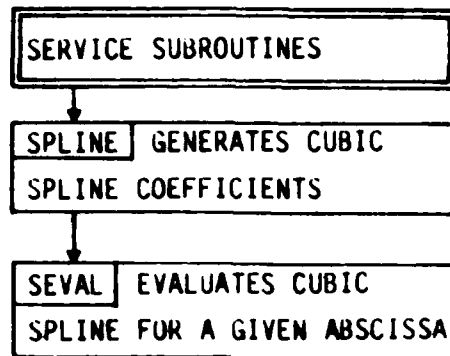


FIGURE C-6 SFFSTAB FLOWCHART CONT'D

## C PROGRAM TO CALCULATE GYROSCOPIC AND DYNAMIC STABILITY

```

C
  DIMENSION ISEG(100),R2(100),R1(100),H(100),RR2(100),RR1(100)
  DIMENSION V(100),AMASS(100),YB(100),AI(100),TI(100),CNAP(100)
  DIMENSION CMAP(100),THETA(100),AD(100),DBCS(100),DCBCS(100)
  DIMENSION DB(100),DBFS(100),DBFSRA(100),CMA(100),CMAL(100)
  DIMENSION CDP(100),AREA(100),CNQP(100),CMQP(100),CMQ(100)
  COMMON/XY1/X1(11),Y1(11)
  COMMON/XY2/X2(11,10),Y2(11,10)
  COMMON/XY3/X3(11,10),Y3(11,10)
  COMMON/XY4/X4(13),Y4(13)
  COMMON/XY5/X5(8),Y5(8)
  COMMON/XY6/X6(5),Y6(5)
  COMMON/XY7/X7(26),Y7(26)
  COMMON/XY8/X8(8),Y8(8)
  COMMON/XYB/XXB(6),YYB(6)
  COMMON/BCD1/B1(11),C1(11),D1(11)
  COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
  COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
  COMMON/BCD4/B4(13),C4(13),D4(13)
  COMMON/BCD5/B5(8),C5(8),D5(8)
  COMMON/BCD6/B6(5),C6(5),D6(5)
  COMMON/BCD7/B7(26),C7(26),D7(26)
  COMMON/BCD8/B8(8),C8(8),D8(8)
  COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
  CHARACTER*6 TITLE(15)

```

```

C
C *****
C
C  ITYPE = 0 - SPHERICAL SEGMENT AND TRUNCATED CONES ARE USED
C           1 - ONLY TRUNCATED CONES ARE USED
C  DEN = DENSITY OF MATERIAL (MASS/VOLUME)(LB SEC**2/IN**4)
C  NSEG = NUMBER OF SEGMENTS
C  DBCS = DISTANCE FROM BASE OF BODY TO CENTROID OF SEGMENT
C  TVOL = TOTAL VOLUME OF BODY(IN**3)
C  TMASS = TOTAL MASS OF BODY(LB SEC**2/IN)
C  CGOB = CENTER OF GRAVITY OF BODY (RELATIVE TO BASE)
C  AIB = AXIAL (POLAR) MOMENT OF INERTIA OF THE BODY(LB SEC**2 IN)
C  TIB = TRANSVERSE MOMENT OF INERTIA OF THE BODY(LB SEC**2 IN)
C  DCBCS = DISTANCE FROM CENTROID OF BODY TO CENTROID OF SEGMENT
C  DB = BASE DIAMETER OF THE SEGMENT
C  CNAT = TOTAL CNA FOR THE BODY
C  CMAT = TOTAL CMA FOR THE BODY (BASED ON AREA AND BASE DIAMETER)
C  CMATL = TOTAL CMA FOR THE BODY (BASED ON AREA AND BODY LENGTH)
C  RA = DISTANCE FROM MOMENT REFERENCE AXIS TO BASE OF BODY
C       (IF RA = 0.0 THE C OF G OF THE BODY IS USED)
C  DBFS = DISTANCE FROM BASE OF BODY TO FRONT FACE OF SEGMENT
C  DBFSRA = DISTANCE FROM FRONT FACE OF SEGMENT TO MOMENT REFERENCE
C           AXIS
C  CMA = CMA FOR A SEGMENT , REFERRED TO A COMMON REFERENCE AXIS
C       (BASED ON AREA AND BASE DIAMETER)
C  CMAL = CMA FOR A SEGMENT , REFERRED TO A COMMON REFERENCE AXIS
C       (BASED ON AREA AND SEGMENT LENGTH)
C  BL = LENGTH OF BODY

```

```

C XCP = CENTER OF PRESSURE AS A FRACTION OF BODY LENGTH
C XM = MOMENT CENTER LOCATION AS A FUNCTION OF BODY LENGTH
C RHO = AIR DENSITY(LB SEC**2/IN**4)
C W = SPIN RATE (RAD/SEC)
C VEL = PROJECTILE VELOCITY(IN/SEC)
C ISG = 1 - CALCULATE W
C      0 - CALCULATE SG
C SG = GYROSCOPIC STABILITY FACTOR
C CDP = NEWTONIAN DRAG COEFFICIENT
C BLUNT = NOSE BLUNTNESS FOR A SPHERICAL SEGMENT
C ESR = EQUIVALENT SAND ROUGHNESS(IN)
C RE = REYNOLDS NUMBER (BASED ON L )
C RES = SAME AS RE
C CRE = CUTOFF REYNOLDS NUMBER
C AR = ADMISSIBLE ROUGHNESS
C U = ABSOLUTE VISCOSITY(LB SEC/IN**2)
C CF = INCOMPRESSIBLE FLAT PLATE SKIN FRICTION COEFFICIENT
C CFCCF = RATIO OF COMPRESSIBLE TO INCOMPRESSIBLE SKIN FRICTION
C        COEFFICIENT
C SB = BODY MAXIMUM FRONTAL AREA(IN**2)
C SS = WETTED AREA OR SURFACE AREA OF THE BODY EXCLUDING THE BASE
C CDF = BODY SKIN FRICTION DRAG COEFFICIENT
C CDO = ZERO LIFT DRAG COEFFICIENT
C CDB = BASE DRAG COEFFICIENT
C AREA = SUFACE AREA OF A SEGMENT
C CNQP = PITCHING DERIVATIVE FOR A SEGMENT
C CMAP = PITCHING MOMENT CURVE SLOPE FOR A SEGMENT
C CNAP = NORMAL FORCE CURVE SLOPE FOR A SEGMENT
C CMQP = PITCHING DERIVATIVE FOR SEGMENT
C CMQ = PITCHING DERVATIVE TRANSFERRED TO A COMMON AXIS
C CMQT = PITCHING DERIVATIVE FOR BODY
C CMPA = DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT
C CMAD = ACCELERATION DERIVATIVE
C SD = DYNAMIC STABILITY FACTOR
C AKB = DIMENSIONLESS AXIAL RADIUS OF GYRATION
C TKB = DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION
C DMCP = DISTANCE FROM MAGNUS CENTER OF PRESSURE TO CENTER OF GRAVITY
C ISPIN = 1 - READ LINER DATA
C TAM = TOTAL ANGULAR MOMENTUM (LB SEC IN)
C WL = SPIN RATE OF LINER (RAD/SEC)
C RPML = SPIN RATE OF LINER (RPM)
C NLS = NUMBER OF LINER SEGMENTS
C TLS = THICKNESS OF LINER SEGMENT
C HLS = HEIGHT OF LINER SEGMENT
C RCS = RADIUS TO CENTROID OF CROSS-SECTIONAL AREA OF LINER SEGMENT
C AMASSL = MASS OF LINER SEGMENT
C TMASSL = TOTAL MASS OF THE LINER
C
C *****
C
C READ AND WRITE INPUT DATA
C
      READ(5,900)(TITLE(I),I=1,15)
      900 FORMAT(13A6,2A1)

```



```
      WRITE(6,801)(TITLE(I),I=1,15)
801  FORMAT(1H ,///,5X,13A6,2A1,/)
      READ(5,10)DEN
10   FORMAT(F10.5)
      READ(5,15)ITYPE,NSEG
15   FORMAT(2I5)
      IF(ITYPE.EQ.1)GO TO 20
      READ(5,25)ISEG(1),R2(1),R1(1),H(1)
25   FORMAT(I5,5X,3F10.5)
      DO 30 I=2,NSEG
      READ(5,35)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
35   FORMAT(I5,5X,5F10.5)
30   CONTINUE
      GO TO 40
20   DO 45 I=1,NSEG
      READ(5,35)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
45   CONTINUE
40   WRITE(6,46)
46   FORMAT(1H1,10X,'***** GYROSCOPIC STABILITY DATA *****',/)
      WRITE(6,50)DEN,ITYPE,NSEG
50   FORMAT(1H ,5X,'DENSITY =' ,F15.8,5X,'ITYPE =' ,I5,5X,
1     'NUMBER OF SEGMENTS =' ,I5)
      WRITE(6,55)
55   FORMAT(1H ,7X,'ISEG' ,9X,'RR2' ,12X,'RR1' ,13X,'R2' ,13X,
1     'R1' ,13X,'H' ,/)
      IF(ITYPE.EQ.1)GO TO 60
      WRITE(6,65)ISEG(1),R2(1),R1(1),H(1)
65   FORMAT(1H ,5X,I5,30X,3(5X,F10.5))
      DO 70 I=2,NSEG
      WRITE(6,75)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
75   FORMAT(1H ,5X,I5,5(5X,F10.5))
70   CONTINUE
      GO TO 80
60   DO 90 I=1,NSEG
      WRITE(6,75)ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I)
90   CONTINUE
80   READ(5,210)RA
210  FORMAT(F10.5)
      READ(5,295)ISG
295  FORMAT(I5)
      WRITE(6,400)RA,ISG
400  FORMAT(1H ,5X,'REFERENCE AXIS =' ,F10.5,5X,'ISG =' ,I5)
      IF(ISG.EQ.1)GO TO 300
      READ(5,305)W,RHO,VEL
305  FORMAT(3F10.5)
      WRITE(6,405)W,RHO,VEL
405  FORMAT(1H ,5X,'W =' ,F20.10,5X,'RHO =' ,F20.15,5X,'VELOCITY =' ,
1     F15.5)
      GO TO 420
300  READ(5,305)SG,RHO,VEL
      WRITE(6,410)SG,RHO,VEL
410  FORMAT(1H ,5X,'SG =' ,F10.5,5X,'RHO =' ,F20.15,5X,'VELOCITY =' ,
1     F15.5)
```

C

C CALCULATE PROPERTIES FOR EACH SEGMENT

C

```

420 CALL COEFF1
    CALL COEFF2
    CALL COEFF3
    CALL COEFF4
    CALL COEFF5
    CALL COEFF6
    CALL COEFF7
    CALL COEFF8
    DO 100 I=1,NSEG
    IF(I.GT.1)GO TO 105
    IF(ITYPE.EQ.1)GO TO 105
    CALL IHSS(ISEG(1),R2(1),R1(1),H(1),DEN,V(1),AMASS(1),YB(1),
1 B,AI(1),TI(1))
    YB(1)=B
    BLUNT=H(1)/R2(1)
    CALL F421123(BLUNT,CNAP(1))
    CALL F422125B(BLUNT,CMAP(1))
    WRITE(6,110)BLUNT,CNAP(1),CMAP(1)
110 FORMAT(1H ,5X,'NOSE BLUNTNESS =',F10.5,5X,'CNAP =',F10.5,
1 5X,'CMAP =',F10.5,/)
    GO TO 100
105 CALL IHTC(ISEG(I),RR2(I),RR1(I),R2(I),R1(I),H(I),DEN,V(I).
1 AMASS(I),YB(I),AI(I),TI(I))
    AD(I)=R2(I)/RR2(I)
    THETA(I)=ATAN((RR2(I)-R2(I))/H(I))/3.14159265*180.
    CALL F421126(THETA(I),CNAP(I),AD(I))
    CALL F422125A(THETA(I),CMAP(I),AD(I))
    WRITE(6,115)THETA(I),AD(I),CNAP(I),CMAP(I)
115 FORMAT(1H ,5X,'THETA =',F10.5,5X,'A/D =',F10.5,5X,
1 'CNAP =',F10.5,5X,'CMAP =',F10.5,/)
100 CONTINUE

```

C

C CALCULATE DISTANCE FROM BASE OF BODY TO CENTROID OF SEGMENT

C

```

    SUM1=H(NSEG)
    NSEGM1=NSEG-1
    DBCS(NSEG)=YB(NSEG)
    DO 120 I=1,NSEGM1
    DBCS(NSEG-I)=YB(NSEG-I)+SUM1
    SUM1=SUM1+H(NSEG-I)
120 CONTINUE

```

C

C CALCULATE THE TOTAL VOLUME AND TOTAL MASS OF BODY

C

```

    TVOL=0.0
    TMASS=0.0
    DO 125 I=1,NSEG
    TVOL=TVOL+V(I)
    TMASS=TMASS+AMASS(I)
125 CONTINUE

```

C

C CALCULATE CENTER OF GRAVITY OF BODY (RELATIVE TO BASE)

```

C      SUM2=0.0
      DO 130 I=1,NSEG
      SUM2=SUM2+DBCS(I)*V(I)
130  CONTINUE
      CGOB=SUM2/TVOL

C
C      CALCULATE AXIAL (POLAR) MOMENT OF INERTIA
C
      AIB=0.0
      DO 135 I=1,NSEG
      AIB=AIB+AI(I)
135  CONTINUE

C
C      CALCULATE DISTANCE FROM CG OF BODY CG OF SEGMENT
C
      DO 140 I=1,NSEG
      DCBCS(I)=ABS(DBCS(I)-CGOB)
140  CONTINUE

C
C      CALCULATE TRANSVERSE MOMENT OF INERTIA USING PARALLEL AXIS THEOREM
C
      TIB=0.0
      DO 145 I=1,NSEG
      TIB=TIB+TI(I)+AMASS(I)*DCBCS(I)**2.
145  CONTINUE

C
C      CALCULATE BASE DIAMETER OF EACH SEGMENT
C
      DO 195 I=1,NSEG
      IF(I.GT.1)GO TO 190
      IF(ITYPE.EQ.1)GO TO 190
      DB(1)=2.*(H(1)*(2.*R2(1)-H(1)))**.5
      GO TO 195
190  DB(I)=2.*RR2(I)
195  CONTINUE
      WRITE(6,150)
150  FORMAT(1H ,6X,'ISEG',8X,'DBCS',11X,'DCBCS',12X,'DB')
      DO 155 I=1,NSEG
      WRITE(6,160)ISEG(I),DBCS(I),DCBCS(I),DB(I)
160  FORMAT(1H ,5X,I5,3(5X,F10.5))
155  CONTINUE
      WRITE(6,165)TVOL
165  FORMAT(1H ,5X,'TOTAL VOLUME OF BODY =',F10.5)
      WRITE(6,170)TMASS
170  FORMAT(1H ,5X,'TOTAL MASS OF BODY =',F10.5)
      WRITE(6,175)CGOB
175  FORMAT(1H ,5X,'CENTER OF GRAVITY OF BODY (RELATIVE TO BASE
      1 F10.5)
      WRITE(6,180)AIB
180  FORMAT(1H ,5X,'AXIAL MOMENT OF INERTIA OF BODY ',F10.5)
      WRITE(6,185)TIB
185  FORMAT(1H ,5X,'TRANSVERSE MOMENT OF INERTIA OF BODY ',F10.5)

```

C CALCULATE CNA FOR THE BODY

C  
 CNAT=0.0  
 DO 200 I=1,NSEG  
 CNAT=CNAT+CNAP(I)\*(DB(I)/DB(NSEG))\*\*2.  
 200 CONTINUE  
 WRITE(6,205)CNAT  
 205 FORMAT(1H ,5X,'CNA FOR THE BODY =',F10.5)

C  
 C CALCULATE DISTANCE FROM BASE OF BODY TO FRONT FACE OF SEGMENT

C  
 SUM3=0.0  
 DO 215 I=1,NSEG  
 DBFS(NSEG+1-I)=SUM3+H(NSEG+1-I)  
 SUM3=SUM3+H(NSEG+1-I)  
 215 CONTINUE

C  
 C CALCULATE DISTANCE FROM SEGMENT FRONT FACE TO MOMENT REFERENCE AXIS

C  
 IF(RA.EQ.0.0)RA=CGOB  
 DO 220 I=1,NSEG  
 DBFSRA(I)=DBFS(I)-RA  
 220 CONTINUE

C  
 C CALCULATE CMA FOR EACH SEGMENT(BASED ON AREA AND BASE DIAMETER)

C  
 DO 225 I=1,NSEG  
 CMA(I)=CMAP(I)+DBFSRA(I)/DB(I)\*CNAP(I)  
 225 CONTINUE

C  
 C CALCULATE CMA FOR EACH SEGMENT(BASED ON AREA AND SEGMENT LENGTH)

C  
 DO 510 I=1,NSEG  
 CMA(I)=CMAP(I)\*DB(I)/H(I)+DBFSRA(I)/H(I)\*CNAP(I)  
 510 CONTINUE

C  
 C CALCULATE CMA FOR THE BODY(BASED ON AREA AND BASE DIAMETER)

C  
 CMAT=0.0  
 DO 230 I=1,NSEG  
 CMAT=CMAT+CMA(I)\*(DB(I)/DB(NSEG))\*\*3.  
 230 CONTINUE

C  
 C CALCULATE THE LENGTH OF THE BODY

C  
 BL=0.0  
 DO 235 I=1,NSEG  
 BL=BL+H(I)  
 235 CONTINUE

C  
 C CALCULATE CMA FOR THE BODY(BASED ON AREA AND BODY LENGTH)

C  
 CMAT=0.0  
 DO 240 I=1,NSEG

```

      CMATL=CMATL+CMAL(I)*(DB(I)/DB(NSEG))**2.*(H(I)/BL)
500 CONTINUE
C
C  CALCULATE THE CENTER OF PRESSURE
C
      XM=(BL-RA)/BL
      XCP=XM-CMATL/CNAT
      WRITE (6,240)
240  FORMAT(1H ,6X,'ISEG',8X,'DBFS',10X,'DBFSRA',12X,'CMA',11X,
1  'CMAL',/)
      DO 245 I=1,NSEG
      WRITE(6,250)ISEG(I),DBFS(I),DBFSRA(I),CMA(I),CMAL(I)
250  FORMAT(1H ,5X,I5,4(5X,F10.5))
245  CONTINUE
      WRITE(6,255)CNAT
255  FORMAT(1H ,5X,'TOTAL CNA FOR THE BODY =' ,F10.5)
      WRITE(6,260)CMAT
260  FORMAT(1H ,5X,'TOTAL CMA FOR THE BODY (BASED ON AREA AND ',
1  'BASE DIAMETER =' ,F10.5)
      WRITE(6,505)CMATL
505  FORMAT(1H ,5X,'TOTAL CMA FOR THE BODY (BASED ON AREA AND ',
1  'BODY LENGTH =' ,F10.5)
      WRITE(6,265)BL
265  FORMAT(1H ,5X,'LENGTH OF THE BODY =' ,F10.5)
      WRITE(6,270)XCP
270  FORMAT(1H ,5X,'CENTER OF PRESSURE AS A FRACTION OF BODY ',
1  'LENGTH =' ,F10.5)
C
C  CALCULATE GYROSCOPIC STABILITY AND SPIN RATE
C
      PI=3.14159265
      IF(ISG.EQ.0)GO TO 275
      W=(SG*PI*RHO*TIB*ABS(CMAT)*DB(NSEG)**3./(2.*AIB**2.))**.5*VEL
      RPM=W*30/PI
      WRITE(6,280)W,RPM
280  FORMAT(1H ,5X,'SPIN RATE (RAD/SEC) =' ,F15.5,5X,
1  'SPIN RATE (RPM) =' ,F15.5)
      GO TO 285
275  SG=2.*AIB**2.*(W/VEL)**2./(PI*RHO*TIB*CMAT*DB(NSEG)**3.)
      WRITE(6,290)SG
290  FORMAT(1H ,5X,'GYROSCOPIC STABILITY FACTOR =' ,F10.5)
      WRITE(6,310)RHO,VEL
310  FORMAT(1H ,5X,'AIR DENSITY =' ,F10.5,5X,'PROJECTILE VELOCITY =' ,
1  F10.5)
C
C  CALCULATE CDP FOR THE FIRST SEGMENT
C
C  SPHERICAL FIRST SEGMENT
C
285  IF(ITYPE.EQ.1)GO TO 600
      CALL F423166(BLUNT,CDP(1))
      GO TO 605
C
C  CYLINDRICAL (TRUNCATED) FIRST SEGMENT

```

```

      A=PI*DB(NSEG)*DB(NSEG)/4
      IF (ITYPE EQ 1) GO TO 620
      AREA(1)=2*PI*R2(1)*H(1)
      GO TO 625
620 AREA(1)=PI*((RR2(1)-R2(1))**2 +H(1)*H(1))** 5*(RR2(1)+R2(1))
625 DO 630 I=2,NSEG
      AREA(I)=PI*((RR2(I)-R2(I))**2 +H(I)*H(I))** 5*(RR2(I)+R2(I))
630 CONTINUE
      SS=0.0
      DO 635 I=1,NSEG
      SS=SS+AREA(I)
635 CONTINUE

C
C  CALCULATE CDF, BODY SKIN FRICTION DRAG COEFFICIENT
C
      CDF=1.02*CF*CFCCF*SS/SB

C
C  CALCULATE CDO, ZERO LIFT DRAG COEFFICIENT
C
      SUMD=0.0
      DO 640 I=1,NSEG
      SUMD=SUMD+CDP(I)*(DB(I)/DB(NSEG))**2.
640 CONTINUE
      CALL F423160(VEL,CDB)
      CDO=CDF+SUMD+CDB

C
C  CALCULATE CNOP,PITCHING DERIVATIVE FOR SEGMENT

```

UNCLASSIFIED

BASED ON BASE AREA AND BASE DIAMETERS REFERRED TO FORWARD  
FACE OF SEGMENT

```

      IF IYPR.EQ.1 GO TO 645
      CALL F21214B(BL,INT(CNQP(1)),
      GO TO 65
      *45 CALL F21214A(THETA(1),AD(1),CNQP(1)
      *50 DO 670 I=2,NSEG
      CALL F21214A(THETA(1),AD(1),CNQP(1))
      *55 CONTINUE

```

A. ARE CMQP, PITCHING DERIVATIVE FOR SEGMENT  
BASED ON BASE AREA AND SQUARE OF BASE DIAMETERS  
REFERRED TO FORWARD FACE OF THE SEGMENT

```

      IF IYPR.EQ.1 GO TO 660
      CALL F21213B(CMQP(1))
      GO TO 665
      *65 CALL F21212A(THETA(1),AD(1),CMQP(1))
      *66 DO 670 I=2,NSEG
      CALL F21212A(THETA(1),AD(1),CMQP(1))
      *70 CONTINUE

```

TRANSFER THE INDIVIDUAL DERIVATIVES TO A COMMON MOMENT CENTER

```

      DO 675 I=1,NSEG
      R=DBFSRA(1)/DB(I)
      CMQ(I)=CMQP(I)-2.*R*CMAP(I)+R*CNQP(I)-2.*R*R*CNAP(I)
      675 CONTINUE

```

CALCULATE CMQ FOR THE ENTIRE BODY  
BASED ON A COMMON REFERENCE AREA AND SQUARED DIAMETER

```

      CMQT=0.0
      DO 680 I=1,NSEG
      CMQT=CMQT+CMQ(I)*((DB(I)/DB(NSEG))**.4
      680 CONTINUE

```

CALCULATE THE MAGNUS MOMENT COEFFICIENT

```

      CALL MAGNUS(BL,DB(NSEG),RES,CGOB,CMPA)

```

CALCULATE CMAD, THE ACCELERATION DERIVATIVE CMAD IN THE HYPERSONIC  
SPEED RANGE IS EQUAL TO ZERO WHEN DETERMINED BY NEWTONIAN THEORY

```

      CMAD=0.0

```

CALCULATE SD, DYNAMIC STABILITY FACTOR

```

      AKB=(AIB/(TMASS*DB(NSEG)**2.))**.5
      TKB=(TIB/(TMASS*DB(NSEG)**2.))**.5
      SD=(2.*(CNAT-CDO)+2.*AKB**(-2.)*CMPA)/(CNAT-2.*CDO-TKB**(-2.)*
      1 (CMQT+CMAD))

```

C WRITE DYNAMIC STABILITY DATA

C

```
WRITE(6,700)
700 FORMAT(1H ,10X,'***** DYNAMIC STABILITY DATA *****',/)
WRITE(6,705)ESR,AR
705 FORMAT(1H ,5X,'EQUIVALENT SAND ROUGHNESS =' ,E12.6,5X,
1 'ADMISSIBLE ROUGHNESS =' ,E12.6)
WRITE(6,710)RES,U
710 FORMAT(1H ,5X,'REYNOLDS NUMBER =' ,E12.6,5X,
1 'ABSOLUTE VISCOSITY =' ,E12.6)
WRITE(6,810)CRE
810 FORMAT(1H ,5X,'CUTOFF REYNOLDS NUMBER =' ,E12.6)
WRITE(6,715)SB,SS
715 FORMAT(1H ,5X,'BODY MAXIMUM FRONTAL AREA =' ,F10.5,5X,
1 'BODY WETTED AREA =' ,F10.5)
WRITE(6,720)AKB,TKB
720 FORMAT(1H ,5X,'DIMENSIONLESS AXIAL RADIUS OF GYRATION =' ,F10.5,
1 5X,'DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION =' ,F10.5,/)
DO 725 I=1,NSEG
WRITE(6,800)I
800 FORMAT(1H ,5X,'PROPERTIES FOR SEGMENT NUMBER ' ,I5)
WRITE(6,730)CDP(I),CNQP(I)
730 FORMAT(1H ,5X,'CDP =' ,F10.5,5X,'CNQP =' ,F10.5)
WRITE(6,735)CMQP(I),CMQ(I)
735 FORMAT(1H ,5X,'CMQP =' ,F10.5,5X,'CMQ =' ,F10.5,/)
725 CONTINUE
WRITE(6,740)CF
740 FORMAT(1H ,5X,'INCOMPRESSIBLE FLAT PLATE SKIN FRICTION ' ,
1 'COEFFICIENT (CF) =' ,F10.5)
WRITE(6,745)CFCCF
745 FORMAT(1H ,5X,'COMPRESSIBLE/INCOMPRESSIBLE SKIN FRICTION ' ,
1 'COEFFICIENT (CFCCF) =' ,F10.5)
WRITE(6,750)CDF
750 FORMAT(1H ,5X,'BODY SKIN FRICTION DRAG COEFFICIENT (CDF) =' ,
1 F10.5)
WRITE(6,755)CDB
755 FORMAT(1H ,5X,'BODY BASE DRAG COEFFICIENT (CDB) =' ,F10.5)
WRITE(6,760)CDO
760 FORMAT(1H ,5X,'BODY ZERO LIFT DRAG COEFFICIENT (CDO) =' ,F10.5)
WRITE(6,765)CMQT
765 FORMAT(1H ,5X,'BODY PITCHING DERIVATIVE (CMQT) =' ,F10.5)
WRITE(6,780)CMPA
780 FORMAT(1H ,5X,'DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT ' ,
1 '(CMPA)=' ,F10.5)
WRITE(6,785)CMAD
785 FORMAT(1H ,5X,'BODY ACCELERATION DERIVATIVE (CMPA) =' ,F10.5)
WRITE(6,790)SD
790 FORMAT(1H ,5X,'DYNAMIC STABILITY FACTOR (SD) =' ,F10.5)
```

C

C CALCULATE STABILITY OF THE BODY

C

```
CALL F611 (CMAT,SD,RHO,TIB,AIB,DB(NSEG),VEL,DEN)
STOP
END
```



```

C
C*****
C
C      SUBROUTINE IHSS(ISEG,R2,R1,H,DEN,V,AMASS,YB,B,AI,TI)
C
C      CALCULATE THE INERTIA PROPERTIES FOR A HOLLOW SPHERICAL SEGMENT
C
C      ISEG = SEGMENT NUMBER
C      R2 = OUTER RADIUS
C      R1 = INNER RADIUS
C      H = HEIGHT OF SEGMENT
C      DEN = DENSITY OF MATERIAL (MASS/VOLUME)
C      V = VOLUME
C      AMASS = MASS
C      YB = DISTANCE FROM REFERENCE AXIS TO CENTROID
C      B = DISTANCE FROM BASE OF SEGMENT TO CENTROID
C      AI = AXIAL (POLAR) MOMENT OF INERTIA
C      TI = TRANSVERSE MOMENT OF INERTIA
C
C      PI=3.1415926
C      V=PI*(R2*R1*R1+H*R2*R2-H*R1*R1-R2**3./3.-2.*R1**3./3.)
C      YB=3.*((R2*R2-R1*R1)*(4.*H*R2-2.*H*H)-(R2*R2-R1*R1)**2.)
C      1 /(4.*((R2*R2-R1*R1)*(3.*H)+3.*R2*R1*R1-R2**3.-2.*R1**3.))
C      AMASS=DEN*V
C      B=YB-R2+H
C      AI=DEN*PI/2.*(8./15.*(R2**5.-R1**5.)+(R2-H)*(R1**4.-R2**4.)
C      1 +2./3.*(R2-H)**3.*(R2*R2-R1*R1))
C      RR1=R2-R1
C      RR2=(R2*R2-R1*R1)
C      RR3=(R2**3.-R1**3.)
C      RR4=(R2**4.-R1**4.)
C      RR5=(R2**5.-R1**5.)
C      TI=DEN*PI*(.25*RR4*(R1-R2+H)+RR2*(1./6.*(R1**3.-(R2-H)**3.)
C      1 +YB*YB*(R1-R2+H)-YB*(R1*R1-(R2-H)**2.))+.25*R2**4.*RR1
C      2 +R2*R2*(1./6.*RR3+YB*YB*RR1-YB*RR2)-3./20.*RR5+.5*YB*RR4
C      3 -YB*YB/3.*RR3)
C      WRITE(6,300)ISEG
C 300 FORMAT(1H ,5X,' PROPERTIES FOR SEGMENT NUMBER ',I5)
C      WRITE(6,301)
C 301 FORMAT(1H ,10X,'HOLLOW SPHERICAL SEGMENT')
C      WRITE(6,302)R2,R1,H
C 302 FORMAT(1H ,5X,'OUTER RADIUS = ',F10.5,5X,'INNER RADIUS = ',
C      1 F10.5,5X,'HEIGHT = ',F10.5)
C      WRITE(6,303)DEN,V,AMASS
C 303 FORMAT(1H ,5X,'DENSITY = ',F15.8,5X,'VOLUME = ',F15.8,5X,
C      1 'MASS = ',F15.8)
C      WRITE(6,304)YB
C 304 FORMAT(1H ,5X,'DISTANCE FROM REFERENCE AXIS TO CENTROID = ',
C      1 F15.8)
C      WRITE(6,305)B
C 305 FORMAT(1H ,5X,'DISTANCE FROM BASE OF SEGMENT TO CENTROID = ',
C      1 F15.8)
C      WRITE(6,306)AI
C 306 FORMAT(1H ,5X,'AXIAL MOMENT OF INERTIA = ',F15.8)

```

```

WRITE(6,307)TI
307 FORMAT(1H ,5X,'TRANSVERSE MOMENT OF INERTIA = ',F15.8)
RETURN
END
C
C*****
C
C      SUBROUTINE IHTC(ISEG,RR2,RR1,R2,R1,H,DEN,V,AMASS,YB,AI,TI)
C
C      CALCULATE THE INERTIA PROPERTIES FOR A HOLLOW TRUNCATED CONE
C
C      ISEG = SEGMENT NUMBER
C      RR2 = OUTER RADIUS AT LARGE END
C      RR1 = INNER RADIUS AT LARGE END
C      R2 = OUTER RADIUS AT SMALL END
C      R1 = INNER RADIUS AT SMALL END
C      H = HEIGHT OF TRUNCATED CONE
C      DEN = DENSITY OF MATERIAL (MASS/VOLUME)
C      V = VOLUME
C      AMASS = MASS
C      YB = DISTANCE FROM CONE BASE TO CENTROID
C      AI = AXIAL(POLAR) MOMENT OF INERTIA
C      TI = TRANSVERSE MOMENT OF INERTIA
C
      PI=3.1415926
      DUMB=(RR2*RR2-RR1*RR1+R2*R2-R1*R1+RR2*R2-RR1*R1)
      V=PI*H/3.*DUMB
      YB=.25*H*(RR2*RR2-RR1*RR1+3.*R2*R2-3.*R1*R1+2.*RR2*R2-
1 2.*RR1*R1)/DUMB
      AMASS=DEN*V
      AI=DEN*PI*H/10.*((RR2**4.+RR2**3.*R2+RR2*RR2*R2+
1 RR2*R2**3.+R2**4.)-(RR1**4.+RR1**3.*R1+RR1*RR1*R1+
2 RR1*R1**3.+R1**4.))
      A1=RR1-R1
      A2=(RR1-R1)**2.
      A3=(RR1-R1)**3.
      A4=(RR1-R1)**4.
      B1=RR2-R2
      B2=(RR2-R2)**2.
      B3=(RR2-R2)**3.
      B4=(RR2-R2)**4.
      TI=(.75*AMASS*(RR2**4.-2.*RR2**3.*B1+2.*RR2**2.*B2-RR2*B3
1 +B4/5.-RR1**4.+2.*RR1**3.*A1-2.*RR1**2.*A2+RR1*A3-A4/5.)
2 +3.*AMASS*(H*H*(RR2*RR2/3.+B2/5.-RR2*B1/2.-RR1*RR1/3.
3 -A2/5.+RR1*A1/2.)+YB*YB*(RR2*RR2+B2/3.-RR2*B1-RR1*RR1
4 -A2/3.+RR1*A1)+YB*H*(-RR2*RR2-B2/2.+4.*RR2*B1/3.
5 +RR1*RR1+A2/2.-4.*RR1*A1/3.)))/DUMB
      WRITE(6,310)ISEG
310 FORMAT(1H ,5X,' PROPERTIES FOR SEGMENT NUMBER ',I5)
      WRITE(6,311)
311 FORMAT(1H ,10X,'HOLLOW TRUNCATED CONE')
      WRITE(6,312)RR2,RR1
312 FORMAT(1H ,5X,'OUTER RADIUS AT LARGE END = ',F10.5,5X,
1 'INNER RADIUS AT LARGE END = ',F10.5)

```

```

      WRITE(6,313)R2,R1
313 FORMAT(1H,5X,'OUTER RADIUS AT SMALL END = ',F10.5X,
1 'INNER RADIUS AT SMALL END = ',F10.5)
      WRITE(6,314)H
314 FORMAT(1H,5X,'HEIGHT = ',F10.5)
      WRITE(6,315)DEN,V,AMASS
315 FORMAT(1H,5X,'DENSITY = ',F15.8X,5X,'VOLUME = ',F15.8X,
1 'MASS = ',F15.8)
      WRITE(6,316)YB
316 FORMAT(1H,5X,'DISTANCE FROM CONE BASE TO CENTROID = ',F15.8)
      WRITE(6,317)AI
317 FORMAT(1H,5X,'AXIAL MOMENT OF INERTIA = ',F15.8)
      WRITE(6,318)TI
318 FORMAT(1H,5X,'TRANSVERSE MOMENT OF INERTIA = ',F15.8)
      RETURN
      END

```

```

C
C .....
C
C .....
C

```

#### SUBROUTINE COEFF1

```

C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.1.1-23
C NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS
C

```

```

      COMMON/XY1/X1(11),Y1(11)
      COMMON/BCD1/B1(11),C1(11),D1(11)
      DATA(X1(I),I=1,11)/0.0000,0.1000,0.2000,0.3000,0.4000,
1 0.5000,0.6000,0.7000,0.8000,0.9000,
2 1.0000/
      DATA(Y1(I),I=1,11)/0.0000,0.1748,0.3497,0.5070,0.6399,
1 0.7517,0.8392,0.9091,0.9580,0.9895,
2 1.0000/
      N=11
      CALL SPLINE(N,X1,Y1,B1,C1,D1)
      RETURN
      END

```

```

C
C .....
C

```

#### SUBROUTINE COEFF2

```

C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.1.1-26
C NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTRUMS
C

```

```

      COMMON/XY2/X2(11,10),Y2(11,10)
      COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
      DIMENSION B(10),C(10),D(10),XXX(10),YYY(10)
      DATA(X2(1,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1 50.000,60.000,70.000,80.000,90.000/
      DATA(Y2(1,I),I=1,10)/2.0000,1.9406,1.7727,1.5140,1.1818,
1 0.8287,0.5035,0.2448,0.0664,0.0000/
      DATA(X2(2,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,

```

```

1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(2,I),I=1,10)/1.9825,1.9161,1.7448,1.4790,1.1678,
1          0.8287,0.5035,0.2448,0.0664,0.0000/
DATA(X2(3,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(3,I),I=1,10)/1.9196,1.8601,1.6853,1.4371,1.1224,
1          0.7867,0.4755,0.2448,0.0664,0.0000/
DATA(X2(4,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(4,I),I=1,10)/1.8217,1.7622,1.6119,1.3601,1.0664,
1          0.7517,0.4510,0.2203,0.0629,0.0000/
DATA(X2(5,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(5,I),I=1,10)/1.6853,1.6329,1.4755,1.2587,0.9825,
1          0.6923,0.4231,0.1958,0.0594,0.0000/
DATA(X2(6,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(6,I),I=1,10)/1.5070,1.4510,1.3217,1.1259,0.8811,
1          0.6259,0.3706,0.1783,0.0559,0.0000/
DATA(X2(7,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(7,I),I=1,10)/1.2867,1.2413,1.1259,0.9580,0.7552,
1          0.5315,0.3252,0.1538,0.0455,0.0000/
DATA(X2(8,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(8,I),I=1,10)/1.0210,0.9895,0.8986,0.7622,0.5909,
1          0.4161,0.2552,0.1224,0.0315,0.0000/
DATA(X2(9,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(9,I),I=1,10)/0.7168,0.6923,0.6224,0.5350,0.4196,
1          0.2937,0.1748,0.0804,0.0210,0.0000/
DATA(X2(10,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(10,I),I=1,10)/0.3671,0.3566,0.3287,0.2797,0.2203,
1          0.1503,0.0909,0.0420,0.0105,0.0000/
DATA(X2(11,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,
1          50.000,60.000,70.000,80.000,90.000/
DATA(Y2(11,I),I=1,10)/0.0000,0.0000,0.0000,0.0000,0.0000,
1          0.0000,0.0000,0.0000,0.0000,0.0000/
N=10
DO 200 J=1,11
DO 210 K=1,10
XXX(K)=X2(J,K)
YYY(K)=Y2(J,K)
210 CONTINUE
CALL SPLINE(N,XXX,YYY,B,C,D)
DO 220 K=1,10
B2(J,K)=B(K)
C2(J,K)=C(K)
D2(J,K)=D(K)
220 CONTINUE
200 CONTINUE
RETURN
END

```

```

C
C*****
C
      SUBROUTINE COEFF3
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.2.1-25A
C  CMAP FOR CONE FRUSTRUMS
C
      COMMON/XY3/X3(11,10),Y3(11,10)
      COMMON/XYB/XXB(6),YYB(6)
      COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
      COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
      DIMENSION B(10),C(10),D(10),XXX(10),YYY(10)
      DATA(X3(1,I),I=1,10)/15.279,20.000,25.000,30.000,40.000,
1      50.000,60.000,70.000,80.000,90.000/
      DATA(Y3(1,I),I=1,10)/-2.400,-1.800,-1.398,-1.149,-0.796,
1      -0.564,-0.388,-0.249,-0.125,0.0000/
      DATA(X3(2,I),I=1,10)/13.219,15.000,20.000,25.000,30.000,
1      40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(2,I),I=1,10)/-2.400,-2.114,-1.599,-1.249,-1.017,
1      -0.723,-0.526,-0.367,-0.183,0.0000/
      DATA(X3(3,I),I=1,10)/11.159,15.000,20.000,25.000,30.000,
1      40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(3,I),I=1,10)/-2.400,-1.807,-1.353,-1.083,-0.900,
1      -0.658,-0.485,-0.350,-0.183,0.0000/
      DATA(X3(4,I),I=1,10)/9.0990,10.000,15.000,20.000,25.000,
1      35.000,45.000,60.000,75.000,90.000/
      DATA(Y3(4,I),I=1,10)/-2.400,-2.118,-1.453,-1.100,-0.903,
1      -0.661,-0.516,-0.339,-0.170,0.0000/
      DATA(X3(5,I),I=1,10)/6.8670,10.000,15.000,20.000,25.000,
1      35.000,45.000,60.000,75.000,90.000/
      DATA(Y3(5,I),I=1,10)/-2.400,-1.668,-1.159,-0.893,-0.737,
1      -0.564,-0.460,-0.315,-0.159,0.0000/
      DATA(X3(6,I),I=1,10)/5.0000,10.000,15.000,20.000,25.000,
1      35.000,45.000,60.000,75.000,90.000/
      DATA(Y3(6,I),I=1,10)/-2.400,-1.239,-0.862,-0.685,-0.588,
1      -0.471,-0.398,-0.287,-0.149,0.0000/
      DATA(X3(7,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
1      40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(7,I),I=1,10)/-1.595,-0.845,-0.613,-0.498,-0.402,
1      -0.350,-0.308,-0.246,-0.138,0.0000/
      DATA(X3(8,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
1      40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(8,I),I=1,10)/-0.900,-0.519,-0.395,-0.339,-0.298,
1      -0.284,-0.249,-0.204,-0.114,0.0000/
      DATA(X3(9,I),I=1,10)/5.0000,10.000,15.000,25.000,35.000,
1      45.000,55.000,65.000,75.000,90.000/
      DATA(Y3(9,I),I=1,10)/-0.436,-0.260,-0.218,-0.194,-0.190,
1      -0.180,-0.163,-0.128,-0.083,0.0000/
      DATA(X3(10,I),I=1,10)/5.0000,10.000,15.000,20.000,30.000,
1      40.000,50.000,60.000,75.000,90.000/
      DATA(Y3(10,I),I=1,10)/-0.118,-0.090,-0.080,-0.083,-0.097,
1      -0.100,-0.093,-0.080,-0.055,0.0000/
      DATA(X3(11,I),I=1,10)/0.0000,10.000,20.000,30.000,40.000,

```

```

1          50.000,60.000,70.000,80.000,90.000/
DATA(Y3(11,I),I=1,10)/0.0000,0.0000,0.0000,0.0000,0.0000,
1          0.0000,0.0000,0.0000,0.0000,0.0000/
DATA(XXB(I),I=1,6)/5.0000,6.8670,9.0990,11.159,13.219,15.279/
DATA(YYB(I),I=1,6)/0.5000,0.4000,0.3000,0.2000,0.1000,0.0000/
N=10
DO 200 J=1,11
DO 210 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
210 CONTINUE
CALL SPLINE(N,XXX,YYY,B,C,D)
DO 220 K=1,10
B3(J,K)=B(K)
C3(J,K)=C(K)
D3(J,K)=D(K)
220 CONTINUE
200 CONTINUE
C
C GENERATE THE CUBIC SPLINE COEFFICIENTS FOR THE BOTTOM OF THE
C GRAPH WHERE CMAP = -2.4 AND A/D IS .5 TO 0
C
N=6
CALL SPLINE(N,XXB,YYB,B3B,C3B,D3B)
RETURN
END
C
C*****
C
SUBROUTINE COEFF4
C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.2.1-25B
C CMAP FOR SPHERICAL SEGMENTS
C
COMMON/XY4/X4(13),Y4(13)
COMMON/BCD4/B4(13),C4(13),D4(13)
DATA(X4(I),I=1,13)/0.0000,0.0250,0.0500,0.1000,0.2000,
1          0.3000,0.4000,0.5000,0.6000,0.7000,
2          0.8000,0.9000,1.0000/
DATA(Y4(I),I=1,13)/0.0000,-.0918,-.1482,-.2188,-.3000,
1          -.3600,-.3988,-.4341,-.4588,-.4800,
2          -.4941,-.5012,-.5012/
N=13
CALL SPLINE(N,X4,Y4,B4,C4,D4)
RETURN
END
C
C*****
C
SUBROUTINE F421123(BLUNT,CNAP)
C
C CALCULATES CNAP FOR A GIVEN NOSE BLUNTNES
C NORMAL-FORCE-CURVE SLOPE FOR SPHERICAL SEGMENTS
C

```

```

COMMON/XY1/X1(11),Y1(11)
COMMON/BCD1/B1(11),C1(11),D1(11)
N=11
CALL SEVAL(BLUNT,CNAP,D1Y0,D2Y0,D3Y0,X1,Y1,B1,C1,D1,N)
RETURN
END

```

```

C
C*****
C
SUBROUTINE F421126(THETA,CNAP,AD)
C
C CALCULATES CNAP FOR A GIVEN SEMICONE ANGLE
C NORMAL-FORCE-CURVE SLOPE FOR CONE FRUSTRUMS
C
COMMON/XY2/X2(11,10),Y2(11,10)
COMMON/BCD2/B2(11,10),C2(11,10),D2(11,10)
DIMENSION CNA(11),XXX(10),YYY(10),B(10),C(10),D(10)
DIMENSION XX(11),BB(11),CC(11),DD(11)
DATA(XX(I),I=1,11)/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,
1 0.9,1.0/
DO 200 J=1,11
DO 210 K=1,10
XXX(K)=X2(J,K)
YYY(K)=Y2(J,K)
210 CONTINUE
DO 220 K=1,10
B(K)=B2(J,K)
C(K)=C2(J,K)
D(K)=D2(J,K)
220 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
CNA(J)=DUMB
200 CONTINUE
CALL SPLINE(11,XX,CNA,BB,CC,DD)
CALL SEVAL(AD,CNAP,D1Y0,D2Y0,D3Y0,XX,CNA,BB,CC,DD,11)
RETURN
END

```

```

C
C*****
C
SUBROUTINE F422125A(THETA,CMAP,AD)
C
C CALCULATES CMAP FOR A GIVEN SEMICONE ANGLE
C CMAP FOR CONE FRUSTRUMS
C
COMMON/XY3/X3(11,10),Y3(11,10)
COMMON/XYB/XXB(6),YYB(6)
COMMON/BCD3/B3(11,10),C3(11,10),D3(11,10)
COMMON/BCD3B/B3B(6),C3B(6),D3B(6)
DIMENSION XX1(11),XX2(11),XX3(10),XX4(9),XX5(8),XX6(7)
DIMENSION XXX(10),YYY(10),B(10),C(10),D(10)
DIMENSION CMA1(11),BB1(11),CC1(11),DD1(11)
DIMENSION CMA2(11),BB2(11),CC2(11),DD2(11)
DIMENSION CMA3(10),BB3(10),CC3(10),DD3(10)

```

```

        DIMENSION CMA4(9),BB4(9),CC4(9),DD4(9)
        DIMENSION CMA5(8),BB5(8),CC5(8),DD5(8)
        DIMENSION CMA6(7),BB6(7),CC6(7),DD6(7)
        DATA(XX1(I),I=1,11)/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,
1          0.9,1.0/
C
C REGION 1 ( THETA .GE. 15.279)
C
        IF(THETA.LT.15.279)GO TO 10
        DO 200 J=1,11
        DO 210 K=1,10
        XXX(K)=X3(J,K)
        YYY(K)=Y3(J,K)
210 CONTINUE
        DO 220 K=1,10
        B(K)=B3(J,K)
        C(K)=C3(J,K)
        D(K)=D3(J,K)
220 CONTINUE
        CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
        CMA1(J)=DUMB
200 CONTINUE
        CALL SPLINE(11,XX1,CMA1,BB1,CC1,DD1)
        CALL SEVAL(AD,CMA1,D1Y0,D2Y0,D3Y0,XX1,CMA1,BB1,CC1,DD1,11)
        GO TO 1000
C
C REGION 2 ( THETA .LT. 15.279 BUT .GE. 13.219)
C
10 IF(THETA.LT.13.219)GO TO 20
        DO 201 J=2,11
        DO 211 K=1,10
        XXX(K)=X3(J,K)
        YYY(K)=Y3(J,K)
211 CONTINUE
        DO 221 K=1,10
        B(K)=B3(J,K)
        C(K)=C3(J,K)
        D(K)=D3(J,K)
221 CONTINUE
        CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
        CMA2(J)=DUMB
        XX2(J)=XX1(J)
201 CONTINUE
        CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
        CMA2(1)=-2.4
        XX2(1)=DUMB
        IF(AD.LT.DUMB)GO TO 2000
        CALL SPLINE(11,XX2,CMA2,BB2,CC2,DD2)
        CALL SEVAL(AD,CMA2,D1Y0,D2Y0,D3Y0,XX2,CMA2,BB2,CC2,DD2,11)
        GO TO 1000
C
C REGION 3 ( THETA .LT. 13.219 BUT .GE. 11.159)
C
20 IF(THETA.LT.11.159)GO TO 30

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```
DO 202 J=3,11
DO 212 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
212 CONTINUE
DO 222 K=1,10
B(K)=B3(J,K)
C(K)=C3(J,K)
D(K)=D3(J,K)
222 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,1)
CMA3(J-1)=DUMB
XX3(J-1)=XX1(J)
202 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
CMA3(1)=-2.4
XX3(1)=DUMB
IF(AD.LT.DUMB)GO TO 2000
CALL SPLINE(10,XX3,CMA3,BB3,CC3,DD3)
CALL SEVAL(AD,CMA3,D1Y0,D2Y0,D3Y0,XX3,CMA3,BB3,CC3,DD3,10)
GO TO 1000
C
C REGION 4 ( THETA .LT. 11.159 BUT .GE. 9.099)
C
30 IF(THETA.LT.9.099)GO TO 40
DO 203 J=4,11
DO 213 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
213 CONTINUE
DO 223 K=1,10
B(K)=B3(J,K)
C(K)=C3(J,K)
D(K)=D3(J,K)
223 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
CMA4(J-2)=DUMB
XX4(J-2)=XX1(J)
203 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
CMA4(1)=-2.4
XX4(1)=DUMB
IF(AD.LT.DUMB)GO TO 2000
CALL SPLINE(9,XX4,CMA4,BB4,CC4,DD4)
CALL SEVAL(AD,CMA4,D1Y0,D2Y0,D3Y0,XX4,CMA4,BB4,CC4,DD4,9)
GO TO 1000
C
C REGION 5 ( THETA .LT. 9.099 BUT .GE. 6.867)
C
40 IF(THETA.LT.6.867)GO TO 50
DO 204 J=5,11
DO 214 K=1,10
XXX(K)=X3(J,K)
YYY(K)=Y3(J,K)
```

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```

214 CONTINUE
DO 224 K=1,10
  B(K)=B3(J,K)
  C(K)=C3(J,K)
  D(K)=D3(J,K)
224 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
CMA5(J-3)=DUMB
XX5(J-3)=XX1(J)
204 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
CMA5(1)=-2.4
XX5(1)=DUMB
IF(AD.LT.DUMB)GO TO 2000
CALL SPLINE(8,XX5,CMA5,BB5,CC5,DD5)
CALL SEVAL(AD,CMA5,D1Y0,D2Y0,D3Y0,XX5,CMA5,BB5,CC5,DD5,8)
GO TO 1000

C
C REGION 6 (THETA .LT. 6.867 BUT .GE. 5.000)
C
50 IF(THETA.LT.5.000)GO TO 60
DO 205 J=6,11
DO 215 K=1,10
  XXX(K)=X3(J,K)
  YYY(K)=Y3(J,K)
215 CONTINUE
DO 225 K=1,10
  B(K)=B3(J,K)
  C(K)=C3(J,K)
  D(K)=D3(J,K)
225 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXX,YYY,B,C,D,10)
CMA6(J-4)=DUMB
XX6(J-4)=XX1(J)
205 CONTINUE
CALL SEVAL(THETA,DUMB,D1Y0,D2Y0,D3Y0,XXB,YYB,B3B,C3B,D3B,6)
CMA6(1)=-2.4
XX6(1)=DUMB
IF(AD.LT.DUMB)GO TO 2000
CALL SPLINE(7,XX6,CMA6,BB6,CC6,DD6)
CALL SEVAL(AD,CMA6,D1Y0,D2Y0,D3Y0,XX6,CMA6,BB6,CC6,DD6,7)
GO TO 1000
60 CMAP=0.0
WRITE(6,4000)THETA
4000 FORMAT(1H,5X,'THETA = ',F10.5,5X,'OUT OF THETA RANGE')
GO TO 1000
2000 WRITE(6,3000)AD,THETA
3000 FORMAT(1H,5X,'A/D = ',F10.5,5X,'WHICH IS OUT OF RANGE
1 ' FOR THETA = ',F10.5)
CMAP=999.99
1000 RETURN
END
C
C*****

```

AO-A179 857

SFFSTAB: A COMPUTER PROGRAM TO CALCULATE THE AERODYNAMIC 2/2  
STABILITY OF A SE (U) DEFENCE RESEARCH ESTABLISHMENT  
SUFFIELD RALSTON (ALBERTA) C A WEICKERT MAR 87  
DRES-SM-1194 F/G 19/18 NL

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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS 1963-A

```

C
C      SUBROUTINE F422125B(BLUNT,CMAP)
C
C      CALCULATES CMAP FOR A GIVEN NOSE BLUNTNESS
C      CMAP FOR SPHERICAL SEGMENTS
C
C      COMMON/XY4/X4(13),Y4(13)
C      COMMON/BCD4/B4(13),C4(13),D4(13)
C      N=13
C      CALL SEVAL(BLUNT,CMAP,D1Y0,D2Y0,D3Y0,X4,Y4,B4,C4,D4,N)
C      RETURN
C      END
C
C
C      *****
C
C      SUBROUTINE F423166(BLUNT,CDP)
C
C      CALCULATE CDP, NEWTONIAN DRAG COEFFICIENT FOR SPHERICAL
C      SEGMENTS REFERRED TO BASE AREA OF SEGMENT
C
C      CDP=BLUNT**2.-2.*BLUNT+2.
C      RETURN
C      END
C
C      *****
C
C      SUBROUTINE F721213B(CMQP)
C
C      CALCULATE CMQP, PITCHING DERIVATIVE FOR SPHERICAL SEGMENTS
C      BASED ON THE BASE AREA AND THE SQUARE OF THE BASE DIAMETER
C
C      CMQP=-.5
C      RETURN
C      END
C
C      *****
C
C      SUBROUTINE F721212(THETA,AD,CMQP)
C
C      CALCULATE THE PITCHING DERIVATIVE CMQP DUE TO INCLINED SIDES
C      OF CONE FRUSTRUMS
C
C      PI=3.1415926
C      RAD=THETA*PI/180.
C      A=6.*AD*AD*(1.-AD*AD)
C      B=-8.*AD*(1.-AD**3.)
C      C=3.*(1.-AD**4.)
C      CMQP=-1./((6.*(SIN(RAD))**2.)*(A*(COS(RAD))**4.+B*(COS(RAD))**2.
1  +C)
C      IF(THETA.GE.5.0)GO TO 100
C      CMQP=0.0
C      WRITE(6,105)
105  FORMAT(1H ,5X,'OUT OF THETA RANGE')

```

```

100 IF(CMQP.GE.-4.8)GO TO 200
    WRITE(6,110)
110 FORMAT(1H ,5X,'OUT OF CMQP RANGE')
200 RETURN
    END

```

```

C
C*****
C

```

```

    SUBROUTINE F721213A(THETA,AD,CMQP)
C
C CALCULATE THE PITCHING DERIVATIVE CMQP FOR THE TOTAL CONE FRUSTRUM
C
    CALL F721212(THETA,AD,CMQP)
    IF(CMQP.EQ.0.0)GO TO 100
    CMQP=CMQP-(AD**4.)/2.
100 RETURN
    END

```

```

C
C*****
C

```

```

    SUBROUTINE F423167S(THETA,AD,CDP)
C
C CALCULATE CDP, DRAG-FORCE COEFFICIENT DUE ONLY TO THE INCLINED
C SIDES OF A CONE FRUSTRUM, BASED ON BODY BASE AREA
C
    PI=3.1415926
    RAD=THETA*PI/180.
    CDP=2.*(SIN(RAD))**2.*(1.-AD*AD)
    RETURN
    END

```

```

C
C*****
C

```

```

    SUBROUTINE F423167T(THETA,AD,CDP)
C
C CALCULATE CDP, DRAG-FORCE COEFFICIENT FOR THE TOTAL CONE FRUSTRUM
C
    PI=3.1415926
    RAD=THETA*PI/180.
    CDP=2.*((SIN(RAD))**2.*(1.-AD*AD)+AD*AD)
    RETURN
    END

```

```

C
C*****
C

```

```

    SUBROUTINE COEFF5
C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.3.1.-68
C COMPRESSIBILITY EFFECT ON TURBULENT SKIN FRICTION
C
    COMMON/XY5/X5(8),Y5(8)
    COMMON/BCD5/B5(8),C5(8),D5(8)
    DATA(X5(I),I=1,8)/0.0000,1.0000,2.0000,3.0000,
1      4.0000,5.0000,6.0000,10.000/

```

```

DATA(Y5(I),I=1,8)/1.0000,0.9271,0.7708,0.6146,
1      0.5000,0.3958,0.3333,0.1289/
CALL SPLINE(8,X5,Y5,B5,C5,D5)
RETURN
END

```

```

C
C*****
C

```

```

SUBROUTINE F423168(VEL,CFCCF)

```

```

C
C CALCULATES CFC/CF, COMPRESSIBILITY EFFECT ON TURBULENT
C SKIN FRICTION
C

```

```

COMMON/XY5/X5(8),Y5(8)
COMMON/BCD5/B5(8),C5(8),D5(8)

```

```

C
C VEL = PROJECTILE VELOCITY(IN/SEC)
C A = SPEED OF SOUND IN AIR(1116.4 FT/SEC)
C AMACH = PROJECTILE VELOCITY (MACH NUMBER)
C

```

```

A=1116.4
AMACH=VEL/(12.*A)
IF(AMACH.GT.10.)GO TO 100
CALL SEVAL(AMACH,CFCCF,D1Y0,D2Y0,D3Y0,X5,Y5,B5,C5,D5,8)
GO TO 200
100 WRITE(6,300)AMACH
300 FORMAT(1H ,10X,'MACH NUMBER =',F10.5,5X,'WHICH IS OUT OF RANGE')
200 RETURN
END

```

```

C
C*****
C

```

```

SUBROUTINE COEFF6

```

```

C
C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.1.5.1-27
C CUTOFF REYNOLDS NUMBER
C

```

```

COMMON/XY6/X6(5),Y6(5)
COMMON/BCD6/B6(5),C6(5),D6(5)
DATA(X6(I),I=1,5)/1.80E03,1.65E04,1.47E05,1.30E06,1.00E07/
DATA(Y6(I),I=1,5)/1.00E05,1.00E06,1.00E07,1.00E08,8.50E08/
CALL SPLINE(5,X6,Y6,B6,C6,D6)
RETURN
END

```

```

C
C*****
C

```

```

SUBROUTINE F415127(AR,CRE)

```

```

C
C CALCULATES CUTOFF REYNOLDS NUMBER
C

```

```

COMMON/XY6/X6(5),Y6(5)
COMMON/BCD6/B6(5),C6(5),D6(5)

```

```

C

```

```

C  AR = ADMISSIBLE ROUGHNESS
C  CRE = CUTOFF REYNOLDS NUMBER
C
      CALL SEVAL(AR,CRE,D1Y0,D2Y0,D3Y0,X6,Y6,B6,C6,D6,5)
      RETURN
      END
C
C*****
C
      SUBROUTINE COEFF7
C
C  GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.1.5.1-26
C  TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN INSULATED
C  FLAT PLATE
C
      COMMON/XY7/X7(26),Y7(26)
      COMMON/BCD7/B7(26),C7(26),D7(26)
      DATA(X7(I),I=1,26)/3.3E05,5.0E05,7.0E05,9.0E05,1.0E06,
1      1.5E06,2.0E06,3.0E06,5.0E06,7.0E06,
2      9.0E06,1.0E07,1.5E07,2.0E07,3.0E07,
3      5.0E07,7.0E07,9.0E07,1.0E08,1.5E08,
4      2.0E08,3.0E08,5.0E08,7.0E08,9.0E08,
5      1.0E09/
      DATA(Y7(I),I=1,26)/.00550,.00505,.00474,.00454,.00445,
1      .00415,.00395,.00369,.00338,.00320,
2      .00306,.00300,.00283,.00270,.00254,
3      .00235,.00223,.00215,.00212,.00199,
4      .00191,.00182,.00170,.00164,.00160,
5      .00158/
      CALL SPLINE(26,X7,Y7,B7,C7,D7)
      RETURN
      END
C
C*****
C
      SUBROUTINE F415126(RE,CF)
C
C  CALCULATE TURBULENT MEAN SKIN FRICTION COEFFICIENT ON AN
C  INSULATED FLAT PLATE
C
      COMMON/XY7/X7(26),Y7(26)
      COMMON/BCD7/B7(26),C7(26),D7(26)
C
C  RE = REYNOLDS NUMBER
C  CF = SKIN FRICTION COEFFICIENT
C
      CALL SEVAL(RE,CF,D1Y0,D2Y0,D3Y0,X7,Y7,B7,C7,D7,26)
      RETURN
      END
C
C*****
C
      SUBROUTINE COEFF8
C

```



C GENERATES CUBIC SPLINE COEFFICIENTS FOR FIG. 4.2.3.1-60  
 C BASE DRAG COEFFICIENT WITH NO BOATTAIL

C  
 COMMON/XY8/X8(8),Y8(8)  
 COMMON/BCD8/B8(8),C8(8),D8(8)  
 DATA(X8(I),I=1,8)/1.5000,2.0000,2.5000,3.5000,  
 1 4.5000,6.0000,7.0000,10.000/  
 DATA(Y8(I),I=1,8)/0.1776,0.1440,0.1168,0.0800,  
 1 0.0560,0.0352,0.0272,0.0110/  
 CALL SPLINE(8,X8,Y8,B8,C8,D8)  
 RETURN  
 END

C  
 C\*\*\*\*\*

C  
 SUBROUTINE F423160(VEL,CDB)  
 C  
 C CALCULATES CDB, BASE DRAG COEFFICIENT(WITH NO BOATTAIL)

C  
 COMMON /XY8/X8(8),Y8(8)  
 COMMON /BCD8/B8(8),C8(8),D8(8)  
 C  
 C VEL = PROJECTILE VELOCITY (IN/SEC)  
 C A = SPEED OF SOUND IN AIR (1116.4 FT/SEC)  
 C AMACH = PROJECTILE VELOCITY (MACH NUMBER)  
 C CDB = BASE DRAG COEFFICIENT  
 C  
 A=1116.4  
 AMACH=VEL/(12.\*A)  
 CALL SEVAL(AMACH,CDB,D1Y0,D2Y0,D3Y0,X8,Y8,B8,C8,D8,8)  
 RETURN  
 END

C  
 C\*\*\*\*\*

C  
 SUBROUTINE F72119A(THETA,AD,CNQP)  
 C  
 C CALCULATE CNQP, PITCHING DERIVATIVE FOR CONE FRUSTRUMS

C  
 PI=3.1415926  
 RAD=THETA\*PI/180.  
 CNQP=2./(3.\*TAN(RAD))\*(2.\*(1-AD\*\*3.)-3.\*AD\*(COS(RAD)\*\*2.)  
 1 \*(1-AD\*AD))  
 IF(THETA.GE.5.0)GO TO 100  
 CNQP=0.0  
 WRITE(6,105)  
 105 FORMAT(1H ,5X,'OUT OF THETA RANGE')  
 100 IF(CNQP.LE.4.4)GO TO 200  
 WRITE(6,110)  
 110 FORMAT(1H ,5X,'OUT OF CNQP RANGE')  
 200 RETURN  
 END

C  
 C\*\*\*\*\*

```

C
C      SUBROUTINE F72119B(BLUNT,CNQP)
C
C      CALCULATE CNQP, PITCHING DERIVATIVE FOR SPHERICAL SEGMENTS
C
C      CNQP=(BLUNT*(2.-BLUNT))**.5
C      RETURN
C      END
C
C*****
C
C      SUBROUTINE MAGNUS(BL,DB,RES,CGOB,CMPA)
C
C      CALCULATE THE DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT
C
C      DMCP=ABS(CGOB-.333*BL)
C      CMPA=26.3*(BL/DB)**2.*DMCP/(RES**.5)
C      RETURN
C      END
C
C*****
C
C      SUBROUTINE F611 (CMAT,SD,RHO,TIB,AIB,DB,VEL,DEN)
C
C      SUBROUTINE TO DETERMINE BODY STABILITY
C
C      DIMENSION TLS(25),HLS(25),RCS(25),AMASSL(25)
C      PI=3.1415926
C      IF(SD.LT.0.0.OR.SD.GT.2.0)GO TO 10
C      IF(CMAT.GT.0.0)GO TO 20
C      WRITE(6,25)CMAT
C 25  FORMAT(1H ,5X,'CMA =' ,F10.5,5X,'(NEGATIVE)')
C      WRITE(6,30)SD
C 30  FORMAT(1H ,5X,'SD =' ,F10.5,5X,'(IN THE RANGE 0-2)')
C      WRITE(6,35)
C 35  FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT ANY SPIN RATE')
C      GO TO 500
C 20  SGI=SD*(2.-SD)
C      SG=1./SGI
C      W=(SG*PI*RHO*TIB*CMAT*DB**3./((2.*AIB**2.))**.5*VEL
C      RPM=W*30./PI
C      WRITE(6,40)CMAT
C 40  FORMAT(1H ,5X,'CMA =' ,F10.5,5X,'(POSITIVE)')
C      WRITE(6,30)SD
C      WRITE(6,65)SGI,SG
C 65  FORMAT(1H ,5X,'SGI =' ,F10.5,5X,'SG =' ,F10.5,5X,'(VALUES ON ',
C      1 'DYNAMIC STABLE/UNSTABLE CURVE)')
C      WRITE(6,45)W,RPM
C 45  FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT SPIN RATES ',
C      1 'GREATER THAN ',E12.6,3X,'(RAD/SEC)',5X,E12.6,3X,'(RPM)')
C
C      CALCULATE THE EQUIVALENT SPIN RATE OF THE SFF LINER
C      BASED ON THE CONSERVATION OF ANGULAR MOMENTUM

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```

C      READ(5,100)ISPIN
100  FORMAT(I5)
      IF(ISPIN.NE.1)GO TO 500
      WRITE(6,200)
200  FORMAT(1H ,//,15X,'LINER DATA',/)
      WRITE(6,205)
205  FORMAT(1H ,8X,'TLS',13X,'HLS',12X,'RCS',10X,'AMASSL',5X,
1    'SEGMENT',/)
      TAM=AIB*W
      READ(5,100)NLS
      TMASSL=0.0
      SUM1=0.0
      DO 105 I=1,NLS
      READ(5,110)TLS(I),HLS(I),RCS(I)
110  FORMAT(3F10.5)
      AMASSL(I)=DEN*TLS(I)*HLS(I)*RCS(I)*2.*PI
      TMASSL=TMASSL+AMASSL(I)
      WRITE(6,210)TLS(I),HLS(I),RCS(I),AMASSL(I),I
210  FORMAT(1H ,3(5X,F10.5),E12.5,I5)
      SUM1=SUM1+AMASSL(I)*RCS(I)**2.
105  CONTINUE
      WL=TAM/SUM1
      RPML=WL*30./PI
      WRITE(6,215)TMASSL
215  FORMAT(1H ,5X,'TOTAL MASS OF THE LINER = ',E15.6,/)
      WRITE(6,220)WL,RPML
220  FORMAT(1H ,5X,'SFF IS DYNAMICALLY STABLE AT CHARGE SPIN ',
1    'RATES GREATER THAN ',E12.6,3X,'(RAD/SEC)',E12.6,3X,'(RPM)')
      GO TO 500
10  IF(CMAT.LT.0.0)GO TO 50
      WRITE(6,40)CMAT
      WRITE(6,55)SD
55  FORMAT(1H ,5X,'SD =',F10.5,5X,'(NOT IN THE RANGE 0-2)')
      WRITE(6,60)
60  FORMAT(1H ,5X,'BODY IS DYNAMICALLY UNSTABLE AT ANY SPINRATE')
      GO TO 500
50  SGI=SD*(2.-SD)
      SG=1./SGI
      SGA=ABS(SG)
      W=(SGA*PI*RHO*TIB*ABS(CMAT)*DB**3./(2.*AIB**2.))**.5*VEL
      RPM=W*30./PI
      WRITE(6,25)CMAT
      WRITE(6,55)SD
      WRITE(6,65)SGI,SG
      WRITE(6,70)W,RPM
70  FORMAT(1H ,5X,'BODY IS DYNAMICALLY STABLE AT SPIN RATES ',
1    'LESS THAN ',E12.6,3X,'(RAD/SEC)',E12.6,3X,'(RPM)')
500  RETURN
      END

```

C

C

C

C

```

SUBROUTINE SPLINE ( N , X , Y , B , C , D )
C
C GENERATES CUBIC SPLINE COEFFICIENTS
C
  REAL X(101) , Y(101) , B(101) , C(101) , D(101)
  NM1 = N - 1
  IF(N-2)60,50,1
1  D(1) = X(2) - X(1)
  C(2) = (Y(2) - Y(1))/D(1)
  DO 10 I=2,NM1
    D(I) = X(I+1) - X(I)
    B(I) = 2.*(D(I-1) + D(I))
    C(I+1) = (Y(I+1) - Y(I))/D(I)
    C(I) = C(I+1) - C(I)
10  CONTINUE
  B(1) = -D(1)
  B(N) = -D(N-1)
  C(1) = 0.0
  C(N) = 0.0
  IF(N-3)11,15,11
11  C(1) = C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))
  C(N) = C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))
  C(1) = C(1)*D(1)*D(1)/(X(4)-X(1))
  C(N) = -C(N)*D(N-1)*D(N-1)/(X(N)-X(N-3))
15  DO 20 I=2,N
    T = D(I-1)/B(I-1)
    B(I) = B(I) - T*D(I-1)
    C(I) = C(I) - T*C(I-1)
20  CONTINUE
  C(N) = C(N)/B(N)
  DO 30 IB = 1,NM1
    I = N - IB
    C(I) = (C(I) - D(I)*C(I+1))/B(I)
30  CONTINUE
  B(N) = (Y(N) - Y(NM1))/D(NM1) + D(NM1)*(C(NM1) + 2.*C(N))
  DO 40 I = 1,NM1
    B(I) = (Y(I+1) - Y(I))/D(I) - D(I)*(C(I+1) + 2.*C(I))
    D(I) = (C(I+1) - C(I))/D(I)
    C(I) = 3.*C(I)
40  CONTINUE
  C(N) = 3.*C(N)
  D(N) = D(N-1)
  RETURN
50  B(1) = (Y(2)-Y(1))/(X(2)-X(1))
  C(1) = 0.0
  D(1) = 0.0
  B(2) = B(1)
  C(2) = 0.0
  D(2) = 0.0
60  RETURN
  END
C
C*****
C

```

SUBROUTINE SEVAL(X0,Y0,D1Y0,D2Y0,D3Y0, X,Y,B,C,D,N)

```
C
C EVALUATES CUBIC SPLINE FOR A GIVEN ABSCISSA
C
  REAL X(100) , Y(100) , B(100) , C(100) , D(100)
  DATA I/1/
  IF(I-N)2,1,1
1  I = 1
2  IF(X0-X(I)) 10,3,3
3  IF(X0-X(I+1)) 30,30,10
10 I = 1
   J = N + 1
20 K = (I+J)/2
   IF(X0-X(K)) 21,22,22
21 J = K
   GO TO 23
22 I = K
23 IF(J - (I+1))30,30,20
30 DX = X0 - X(I)
   Y0 = Y(I) + DX*(B(I) + DX*(C(I) + DX*D(I)))
   D1Y0 = B(I) + DX*(2.*C(I) + 3.*D(I)*DX)
   D2Y0 = 2.*C(I) + 6.*D(I)*DX
   D3Y0 = 6.*D(I)
  RETURN
  END
```

SFFSTAB INPUT

TITLE CARD (13A6, 2A1)

--

BODY MATERIAL DENSITY (F10.5)

DEN	
-----	--

SEGMENT CARD (2I5)

ITYPE	NSEG	
-------	------	--

ITYPE = 0 - spherical segments and truncated cones are used  
 1 - only truncated cones are used  
 NSEG = number of segments

INDIVIDUAL SEGMENT CARDS - AS REQUIRED

SPHERICAL SEGMENT CARD (I5, 5X, 3F10.5) - AS REQUIRED

ISEG		R2	R1	H	
------	--	----	----	---	--

ISEG = segment number  
 R2 = outer radius  
 R1 = inner radius  
 H = segment height

TRUNCATED CONE SEGMENT CARD (I5, 5X, 5F10.5) - AS REQUIRED

ISEG		RR2	RR1	R2	R1	H	
------	--	-----	-----	----	----	---	--

ISEG = segment number  
 RR2 = outer radius at large end  
 RR1 = inner radius at large end  
 R2 = outer radius at small end  
 R1 = inner radius at small end  
 H = segment height

REFERENCE AXIS (F10.5)

RA = 0.0 if C of G is to be used

RA			
----	--	--	--

10

GYROSCOPIC STABILITY CARD (I5)

ISG			
-----	--	--	--

5

ISG = 0 - calculate SG  
 = 1 - calculate W

CARD FOR ISG = 0 (3F10.5) - AS REQUIRED

W	RHO	VEL	
---	-----	-----	--

10

20

W = spin rate (RAD/SEC)  
 RHO = air density (lb sec<sup>2</sup>/in<sup>4</sup>)  
 VEL = body velocity (in/sec)

CARD FOR ISG = 1 (3F10.5) - AS REQUIRED

SG	RHO	VEL	
----	-----	-----	--

10

20

SG = gyroscopic stability factor

DRAG PARAMETERS CARD (2E10.5)

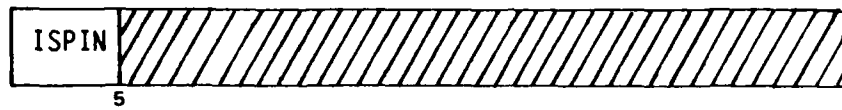
U	ESR	
---	-----	--

10

20

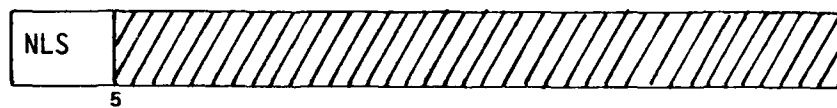
U = absolute viscosity (lb sec/in<sup>2</sup>)  
 ESR = equivalent sand roughness (in)

(I5)



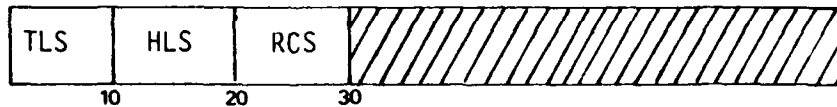
ISPIN = 1 → calculates charge spin rate

(I5)



NLS = number of liner segments

(3F10.5)

0  
0  
0ONLY  
FOR  
ISPIN = 1

Repeat for each segment

TLS = thickness of segment

HLS = height of segment

RCS = radius of centroid of cross-sectional  
area of liner segment



SAMPLE PROBLEM INPUT

BASELINE DESIGN SHOT #01

.000837

0 5

1	.3564	0.0	.2152		
2	.4048	0.0	.3193	0.0	.2024
3	.4576	0.0	.4048	0.0	.3107
4	.4704	0.0	.4576	0.0	1.1717
5	.5488	0.0	.4704	0.0	.6942

0.0

1

1.0.000000115 92262.

2.5932E-09 .16E-03

1

20

.121	.1	.05
.122	.1	.15
.123	.1	.25
.124	.1	.35
.125	.1	.45
.126	.1	.55
.127	.1	.65
.128	.1	.75
.129	.1	.85
.129	.1	.95
.129	.1	1.05
.130	.1	1.15
.130	.1	1.25
.129	.1	1.35
.129	.1	1.45
.128	.1	1.55
.127	.1	1.65
.125	.1	1.75
.124	.1	1.85
.121	.1	1.95

## SAMPLE PROBLEM OUTPUT

## BASELINE DESIGN SHOT #01

## 1 \*\*\*\*\* GYROSCOPIC STABILITY DATA \*\*\*\*\*

DENSITY = .00083700 ITYPE = 0 NUMBER OF SEGMENTS = 5 H  
 1SEG RR1 R2 R1  
 1 .35640 .00000 .21520  
 2 .40480 .00000 .20240  
 3 .45760 .00000 .31070  
 4 .47040 .00000 1.17170  
 5 .54880 .00000 .69420  
 REFERENCE AXIS = .00000 1SG = 1 VELOCITY = 92262.00000  
 SG = 1.00000 RHO = .0000011499999

## PROPERTIES FOR SEGMENT NUMBER 1

## HOLLOW SPHERICAL SEGMENT

OUTER RADIUS = .35640 INNER RADIUS = .00000 HEIGHT = .21520  
 DENSITY = .00083700 VOLUME = .03846823 MASS = .00003220  
 DISTANCE FROM REFERENCE AXIS TO CENTROID = .22600125  
 DISTANCE FROM BASE OF SEGMENT TO CENTROID = .08480125  
 AXIAL MOMENT OF INERTIA = .00000135  
 TRANSVERSE MOMENT OF INERTIA = .00000073  
 NOSE BLUNTNESS = .60382 CMAP = -.45965

## PROPERTIES FOR SEGMENT NUMBER 2

## HOLLOW TRUNCATED CONE

OUTER RADIUS AT LARGE END = .40480 INNER RADIUS AT LARGE END = .00000  
 OUTER RADIUS AT SMALL END = .31930 INNER RADIUS AT SMALL END = .00000  
 HEIGHT = .20240  
 DENSITY = .00083700 VOLUME = .08373579 MASS = .00007009  
 DISTANCE FROM CONE BASE TO CENTROID = .09327055  
 AXIAL MOMENT OF INERTIA = .00000470  
 TRANSVERSE MOMENT OF INERTIA = .00000259  
 THETA = 22.90069 A/D = .78878 CMAP = .62997 CMAP = -.21029

## PROPERTIES FOR SEGMENT NUMBER 3

## HOLLOW TRUNCATED CONE

OUTER RADIUS AT LARGE END = .45760 INNER RADIUS AT LARGE END = .00000  
 OUTER RADIUS AT SMALL END = .40480 INNER RADIUS AT SMALL END = .00000  
 HEIGHT = .31070  
 DENSITY = .00083700 VOLUME = .18171506 MASS = .00015210  
 DISTANCE FROM CONE BASE TO CENTROID = .14901710  
 AXIAL MOMENT OF INERTIA = .00001423  
 TRANSVERSE MOMENT OF INERTIA = .00000833  
 THETA = 9.64464 A/D = .88462 CMAP = .41093 CMAP = -.11247

PROPERTIES FOR SEGMENT NUMBER 4  
 HOLLOW TRUNCATED CONE  
 OUTER RADIUS AT LARGE END = .47040 INNER RADIUS AT LARGE END = .00000  
 OUTER RADIUS AT SMALL END = .45760 INNER RADIUS AT SMALL END = .00000  
 HEIGHT = 1.17170  
 DENSITY = .00083700 VOLUME = .79255570 MASS = .00066337  
 DISTANCE FROM CONE BASE TO CENTROID = .58046321  
 AXIAL MOMENT OF INERTIA = .00007143  
 TRANSVERSE MOMENT OF INERTIA = .00011159  
 THETA = .62589 OUT OF THETA RANGE  
 THETA = .62589 A/D = .97279 CNAP = .09950 CMAP = .00000

PROPERTIES FOR SEGMENT NUMBER 5  
 HOLLOW TRUNCATED CONE  
 OUTER RADIUS AT LARGE END = .54880 INNER RADIUS AT LARGE END = .00000  
 OUTER RADIUS AT SMALL END = .47040 INNER RADIUS AT SMALL END = .00000  
 HEIGHT = .69420  
 DENSITY = .00083700 VOLUME = .56747804 MASS = .00047498  
 DISTANCE FROM CONE BASE TO CENTROID = .32933503  
 AXIAL MOMENT OF INERTIA = .00006228  
 TRANSVERSE MOMENT OF INERTIA = .00005010  
 THETA = 6.44344 A/D = .85714 CNAP = .51445 CMAP = -.20205

ISEG	DBCS	DCBCS	DB
1	2.46380	1.35312	.65447
2	2.26987	1.15919	.80960
3	2.01492	.90424	.91520
4	1.27466	.16398	.94080
5	.32934	.78135	1.09760

TOTAL VOLUME OF BODY = 1.66395  
 TOTAL MASS OF BODY = .00139  
 CENTER OF GRAVITY OF BODY (RELATIVE TO BASE) = 1.11068  
 AXIAL MOMENT OF INERTIA OF BODY = .00015  
 TRANSVERSE MOMENT OF INERTIA OF BODY = .00076  
 CNA FOR THE BODY = 1.51543

ISEG	DBFS	DBFSRA	CMA	CMAI
1	2.59420	1.48352	1.44936	4.40782
2	2.37900	1.26832	.77662	3.10648
3	2.17660	1.06592	.36613	1.07849
4	1.86590	.75522	.07988	.06414
5	.69420	-.41648	-.39725	-.62809

TOTAL CMA FOR THE BODY = 1.51543  
 TOTAL CMA FOR THE BODY (BASED ON AREA AND BASE DIAMETER = .48424  
 TOTAL CMA FOR THE BODY (BASED ON AREA AND BODY LENGTH = .20488  
 LENGTH OF THE BODY = 2.59420  
 CENTER OF PRESSURE AS A FRACTION OF BODY LENGTH = .43666  
 SPIN RATE (RAD/SEC) = 5612.35498 SPIN RATE (RPM) = 53594.04440  
 OUT OF THETA RANGE  
 OUT OF THETA RANGE  
 \*\*\*\*\* DYNAMIC STABILITY DATA \*\*\*\*\*  
 EQUIVALENT SAND ROUGHNESS = .160000E-03 ADMISSIBLE ROUGHNESS = .162137E+05  
 REYNOLDS NUMBER = .106142E+08 ABSOLUTE VISCOSITY = .259320E-08  
 CUTOFF REYNOLDS NUMBER = .982166E+06  
 BODY MAXIMUM FRONTAL AREA = .94619 BODY WETTED AREA = 7.48865  
 DIMENSIONLESS AXIAL RADIUS OF GYRATION = .30295 DIMENSIONLESS TRANSVERSE RADIUS OF GYRATION = .67242

PROPERTIES FOR SEGMENT NUMBER 1  
 CDP = 1.15696 CNQP = .91817  
 CMQP = -.50000 CMQ = -4.98937

PROPERTIES FOR SEGMENT NUMBER 2  
 CDP = .11442 CNQP = .41000  
 CMQP = -.14031 CMQ = -1.93131

PROPERTIES FOR SEGMENT NUMBER 3  
 CDP = .01221 CNQP = .21421  
 CMQP = -.06286 CMQ = -.66824

PROPERTIES FOR SEGMENT NUMBER 4  
 CDP = .00001 CNQP = .00000  
 CMQP = .00000 CMQ = -.12824

PROPERTIES FOR SEGMENT NUMBER 5  
 CDP = .00668 CNQP = .39492  
 CMQP = -.18459 CMQ = -.63591

INCOMPRESSIBLE FLAT PLATE SKIN FRICTION COEFFICIENT (CF) = .00447  
 COMPRESSIBLE/INCOMPRESSIBLE SKIN FRICTION COEFFICIENT (CFCCF) = .29972  
 BODY SKIN FRICTION DRAG COEFFICIENT (CDF) = .01080  
 BODY BASE DRAG COEFFICIENT (CDB) = .02795  
 BODY ZERO LIFT DRAG COEFFICIENT (CDO) = .52754  
 BODY PITCHING DERIVATIVE (CMOT) = -2.22958  
 DERIVATIVE OF THE MAGNUS MOMENT COEFFICIENT (CMA)= .01113  
 BODY ACCELERATION DERIVATIVE (CMA) = .00000  
 DYNAMIC STABILITY FACTOR (SD) = .41145  
 CMA = .48424 (POSITIVE)  
 SD = .41145 (IN THE RANGE 0-2)  
 SGI = .65361 SG = 1.52996 (VALUES ON DYNAMIC STABLE/UNSTABLE CURVE)  
 BODY IS DYNAMICALLY STABLE AT SPIN RATES GREATER THAN .694200E+04 (RAD/SEC)  
 .662912E+05 (RPM)

## LINER DATA

TLS	HLS	RCS	AMASSL	SEGMENT
.12100	.10000	.05000	.31817E-05	1
.12200	.10000	.15000	.96240E-05	2
.12300	.10000	.25000	.16172E-04	3
.12400	.10000	.35000	.22824E-04	4
.12500	.10000	.45000	.29582E-04	5
.12600	.10000	.55000	.36445E-04	6
.12700	.10000	.65000	.43413E-04	7
.12800	.10000	.75000	.50487E-04	8
.12900	.10000	.85000	.57665E-04	9
.12900	.10000	.95000	.64449E-04	10
.12900	.10000	1.05000	.71234E-04	11
.13000	.10000	1.15000	.78622E-04	12
.13000	.10000	1.25000	.85459E-04	13
.12900	.10000	1.35000	.91586E-04	14
.12900	.10000	1.45000	.98370E-04	15
.12800	.10000	1.55000	.10434E-03	16
.12700	.10000	1.65000	.11020E-03	17
.12500	.10000	1.75000	.11504E-03	18
.12400	.10000	1.85000	.12064E-03	19
.12100	.10000	1.95000	.12409E-03	20
TOTAL MASS OF THE LINER = .133343E-02				
SFF IS DYNAMICALLY STABLE AT CHARGE SPIN RATES GREATER THAN .404143E+03 (RAD/SEC) .385928E+04 (RPM)				

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13. ABSTRACT  An aerodynamic stability computer program (SFFSTAB) has been developed for calculating the spin rate required for stabilization of a self-forging fragment. An aerodynamic stability criterion which combined gyroscopic and dynamic stability was used together with a technique for calculating aerodynamic coefficients. SFFSTAB is a useful tool for conducting aerodynamic stability parameter studies for different fragment shapes. Complete documentation of the computer program including sample problem, flowchart and FORTRAN listing is provided.			

## KEY WORDS

SELF-FORGING FRAGMENT, SPIN, SPIN STABILIZATION, AERODYNAMIC STABILITY, EXPLOSIVES, FLASH X-RAY

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